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DESCRIPTIVE MODEL OF A SHIPBOARD ECOLOGICAL SYSTEM

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NAVAL POSTGRADUATE SCHOOL
Monterey, California

THESIS

DESCRIPTIVE MODEL OF A SHIPBOARD ECOLOGICAL SYSTEM

by

John Odgers Miner, Jr.

Thesis Advisor: Marlin U. Thomas

June 1972

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Descriptive Model of a Shipboard Ecological System

by

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Lieutenant Commander, United States Navy
B.M.E., Cornell University, 1964

Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN OPERATIONS RESEARCH

from the

NAVAL POSTGRADUATE SCHOOL
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ABSTRACT

An investigation into the problems of economically processing sewage on board Naval ships resulted in the development of two computer simulations employing Monte Carlo analysis to describe the generation of sewage. Simulation one was based on a non-homogeneous Poisson process. For simulation two, an empirical distribution describing the arrival behavior of sewage to the holding/processing unit over a 24 hour period was applied to known data on sewage generation.

Results of the two simulations were compatible with one another. Aside from pointing out a most feasible combination of holding tank capacity, processor rate and processing policy, the simulations also indicated that a revision of the Navy's design parameter for the daily per capita sewage generation rate was in order. The simulations were designed so that use by others with their own data would be an easy matter.

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I. INTRODUCTION

A. BACKGROUND

During the time between the conception of this thesis and its completion, significant changes in both policy and attitude have been made by the Navy in the field of pollution abatement. These alterations have resulted from increasing public pressure for the ecological restoration of U.S. inland waters and subsequent congressional legislation which outlined future restrictions to all seagoing vessels and watercraft. More specifically, in August 1971, the Chief of Naval Operations stated "that the water pollution abatement program for Naval ships has as its long term goal the installation of two basic systems aboard ship:

1. A Marine Sanitation Device (MSD) which processes sewage to an acceptable effluent;

2. A Collection, Holding and Transfer (CHT) System which is designed to transfer all liquid wastes (except oil) ashore or to a barge."

Late in 1971, however, the Senate issued further restrictions to vessels to the extent that, by the year 1981, there shall be no toxic effluent discharge, whatsoever, from any ship into U.S. inland waters. As a result, Naval design efforts refocused primarily on the development of a Collection, Holding and Transfer System. This shift in emphasis was also aided by the fact that prototypes of Marine Sanitation Devices had suffered from low system

reliability and excessive costs. The present goal, then, of the Navy is the development of a sewage holding tank system with the capacity to retain 12 hours of sewage generated by a full complement crew and with the capability of transferring such sewage to an external processing facility ashore. Such a system is to be installed in all ships remaining in the fleet after 1977.

B. STATEMENT OF THE PROBLEM

It is the contention of the author that neither strictly holding sewage for later transfer, nor immediately processing the sewage internally as it arrives to the processing unit, is the most feasible economic solution to pollution abatement. A policy of holding sewage and transferring it to some other processing station would greatly hamper the Navy's capability to act as a mobile self-sustained unit; likewise, the policy of rapid processing aboard would require expensive units of high output and reliability. It is believed that viable trade-offs can be realized through a combination of the two, employing a smaller, cheaper processor which could operate at a lower processing rate, and a smaller holding tank that could absorb sewage flow during peak periods of the day.

A second contention, that is perhaps more germaine to the current Navy policy of a twelve hour holding system with subsequent transfer, is the belief that the presently accepted daily per captia rate of 30 gal/man/day of sewage

generation is over estimated [Ref. 5]. The parameter was determined from data gathered by the Marine Engineering Laboratory on the daily sewage generation rates per man on board four ships. By reasoning that "any treatment unit used aboard a Naval vessel must be designed to operate with a full complement 24 hours per day," the MEL Report [Ref. 18] recommended that the rates measured be doubled for design purposes. This resulted in a figure of 30 gal/man/day. Since the original figures were obtained on a per capita basis, and there was little variation, it is felt by the author that more accurate results could be obtained by applying the unmodified data to a model which also considers the traffic pattern of personnel using the facilities over a period of time.

It was the purpose of this study, then, to investigate the problem of sewage generation and processing aboard a Naval ship, and to develop a model which would best describe such a process. This model would be useful in aiding decisions on the selection of the most feasible treatment system.

The approach taken, as presented in this thesis, was to first formulate the problem analytically and to compare it with other research performed in related cases. A computer simulation was then developed, motivated by a similar study done for the air lines regarding sewage handling on board large jumbo jets [Ref. 9]. The simulation, its methodoligies and how it can be used are described in Chapter III. The

simulation provides a sensitive model which illustrates the trade-offs obtainable through any treatment policy tested. It also reinforces the contention that a revision of sewage generation rates, combined with closer analysis, can lead to savings in holding tank size.

It should be noted that a simulation is no stronger than the basic assumptions made regarding its underlying structure, and that such assumptions should be examined critically. With this in mind, the simulations were developed using the best information available; however, they were also made flexible enough so that, should a designer have better arrival data or other policies to test, such information could be easily read into the program to give useful, real world results.

II. PROBLEM FORMULATION

A. THE BASIC MODEL

The overall process of generating sewage over a specific length of time, storing it and/or processing it can be described analytically. Further, it can be related to a group of similar problems that are generally classified as storage problems, examples of which are the collection and storage of water in a reservoir subject to some release rule, and inventory problems in which demand is random. Any such process in which either the input or output is random comes under the category of a stochastic process.

Such is the case with the sewage storage and processing problem, in which the input, $\chi(t)$, (see Figure 1) into a storage tank is random in nature. Here $\chi(t)$ represents the amount of sewage generated by the ship's company at discrete points in time, t, corresponding to, say, hours or minutes. Two important characteristics of this input are 1) its time

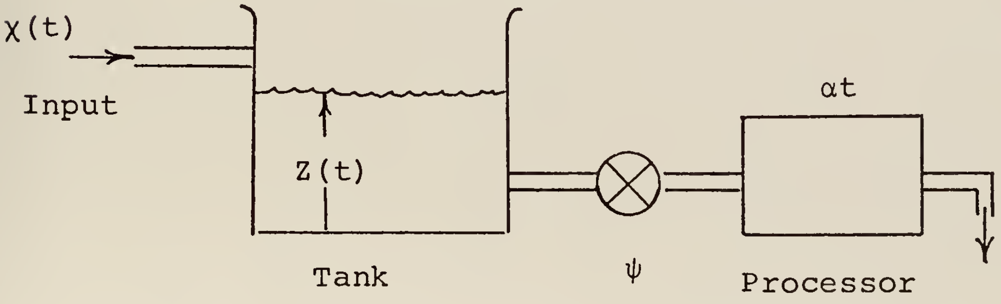


Figure 1. Schematic of System.

dependent arrival behavior to the tank, and 2) its overall distribution. It is assumed that X(t) is independent and identically distributed for different values of t. For this discussion, X(t) is assumed to be solely bodily waste; however the model could also be expanded to include "hotel" and galley waste.

Z(t) represents the total amount of sewage in the storage tank also at time t. Aside from being a function of the input random variable, X(t), it is also a function of the rate, α, at which the sewage is processed, and the particular "release rule" or processing policy, ψ, that is applied. The processing policy is essentially a switching function which turns the processor on or off based on either a time plan (e.g. on at certain hours of the day), a tank level plan (e.g. turn on when the level of sewage reaches a certain height), or a combination of the two.

At certain times of the day, the processing rate may exceed the input, X(t), while at other times it may lag it. If the processing rate is much lower than the input rate, Z(t) will behave like a sum of independent random variables. For such a case, the tank would be expected to overflow. If the processing rate is much higher than the input, then the tank may never fill at all, and Z(t) will behave more deterministically (or equal zero). One of the questions to be answered, then, is what is the optimal processing rate?

In general, Z(t) may be described as follows:

$$Z(t) = \begin{cases} K & \text{if } Z(t-1)+X(t)-\alpha t \geq K \\ Z(t-1)+X(t)-\alpha t, & \text{if } 0<Z(t-1)+X(t)-\alpha t<K \\ Z(t-1)+X(t), & \text{if } \alpha=0 \\ 0 & \text{if } Z(t-1)+X(t)-\alpha t \leq 0 \end{cases} \qquad (1)$$

where K is the capacity of the tank.

This formulation includes two special cases. The first is the event that overflow occurs in which case:

$$Z(t) = \begin{cases} Z(t-1)+X(t)-\alpha t, & \text{if } Z(t-1)+X(t)-\alpha t<K \\ K & \text{if } Z(t-1)+X(t)-\alpha t \geq K \end{cases} \qquad (2)$$

Here the overflow is $Z(t-1)+X(t)-\alpha t-K$. The second case is the event that processing empties the tank completely, so that:

$$Z(t) = \begin{cases} Z(t-1)+X(t)-\alpha t, & \text{if } Z(t-1)+X(t)-\alpha t>0 \\ 0 & \text{if } Z(t-1)+X(t)-\alpha t \leq 0 \end{cases} \qquad (3)$$

B. OTHER RELATED STUDIES

Equation (1) through (3) are not unique to the sewage generation and collection problem. Rather, they parallel those proposed by Moran, Gani, and others [Refs. 15, 8, 10] under the broader discipline of the stochastic theory of reservoirs or storage, an approach which has attracted considerable theoretical interest, but has seen less application.

Initially the theory, as proposed by Moran, required the inflow, X(t), to have a known continuous probability distribution and to be mutually independent of the inflow for

any other value of t (all of which have the same distribution). The level in the tank, $Z(t)$, is subject to some release rule, ψ, and the sequence $\{Z(t+1), t>0\}$ is a Markov process, with state transition probabilities that can be computed from the inflow probability distribution. Considerable effort has been expended in finding solutions to the steady state distribution of $Z(t)$ for both continuous and discrete cases.

These initial studies were extended by a number of authors. One such work by F. M. Lloyd [Ref. 12] showed that the theory need not be limited to inflows that were mutually independent, but that it could also be applied to serially correlated inputs with the results forming a bivariate Markov Chain. Ali Khan and Gani [Ref. 1] carried this study one step further to consider the time dependent solution to the same model.

An excellent example of the application of the above theory which is closely related to the sewage problem is the work by Avi-Itzhak and Ben-Tuvia [Ref. 3]. Here the authors studied the problem of "how big a reservoir to build and what should the pumping capacity be, such that the cost per cubic meter of water is a minimum." In order to obtain their solution, however, the authors first had to assume an approximate distribution for the daily input to the reservoir as well as know the costs involved in operating the system.

In all of the above cases the underlying requirement is that the distribution of $X(t)$ is known or can be approximated by a sequence of discrete distributions.

III. MODELING THROUGH SIMULATION

A. JUSTIFICATION OF SIMULATION

The storage theory approach described above leads to perhaps the most precise solution to the sewage storage problem. It has, however, certain drawbacks which preclude its immediate implementation. The first of these is the lack of real world information and data with which to derive the necessary matrix of transition probabilities. Secondly, the mathematics involved are difficult and cumbersome. This is especially so when one is attempting to solve the problem for different processing policies ("release rules") and processing rates, each of which would require its own transition matrix. Thirdly, the complexity of the distribution of $X(t)$, the input variable, whose stationarity over time is questionable, would require partitioning the process in order to arrive at a solution. Such a non-homogeneous process would only further complicate the analysis. Lastly, the problem of a reversing boundary brought about by abrupt changes in processing rate, according to the processing policy used, would add even another dimension to an already difficult problem.

Taking the above into consideration, it was decided that a computer simulation involving Monte Carlo analysis was at least a justifiable, if not preferable, alternative. Most important to the justification of a simulation was the fact that it could be made amenable to any alterations in

processing policies and processing rates. It is also adaptable to adjustments in the input distribution if and when additional data on the arrival patterns of sewage inputs are obtained. These characteristics have been incorporated into the simulations developed in this study.

B. DESCRIPTION OF THE SIMULATIONS DEVELOPED

Two computer simulations were developed using FORTRAN IV for runs on the IBM 360/67 computer. The simulations differed only in the method of Monte Carlo analysis used to generate the sewage input distribution, $\chi(t)$, which was then applied to the basic mathematical model described in Chapter II (equations (1) - (3)). For simulation one, $\chi(t)$ was determined by assuming a non-homogeneous Poisson process. For simulation two, an empirical distribution describing the arrival behavior of sewage to the tank over a 24 hour period was applied to known data on sewage generation. The techniques and mathematics involved are described in subsections 2 and 3 following an overall description of the basic simulation (subsection 1).

1. Basic Design Common to Both Simulations

Aside from the methods used to generate observations of the sewage input, the two simulations were identical in the way the sewage was processed from the holding tank. (See general flow chart of the simulations, Figure 2.) First it was assumed that the holding tank used in the models had sufficient capacity so that overflow was not a

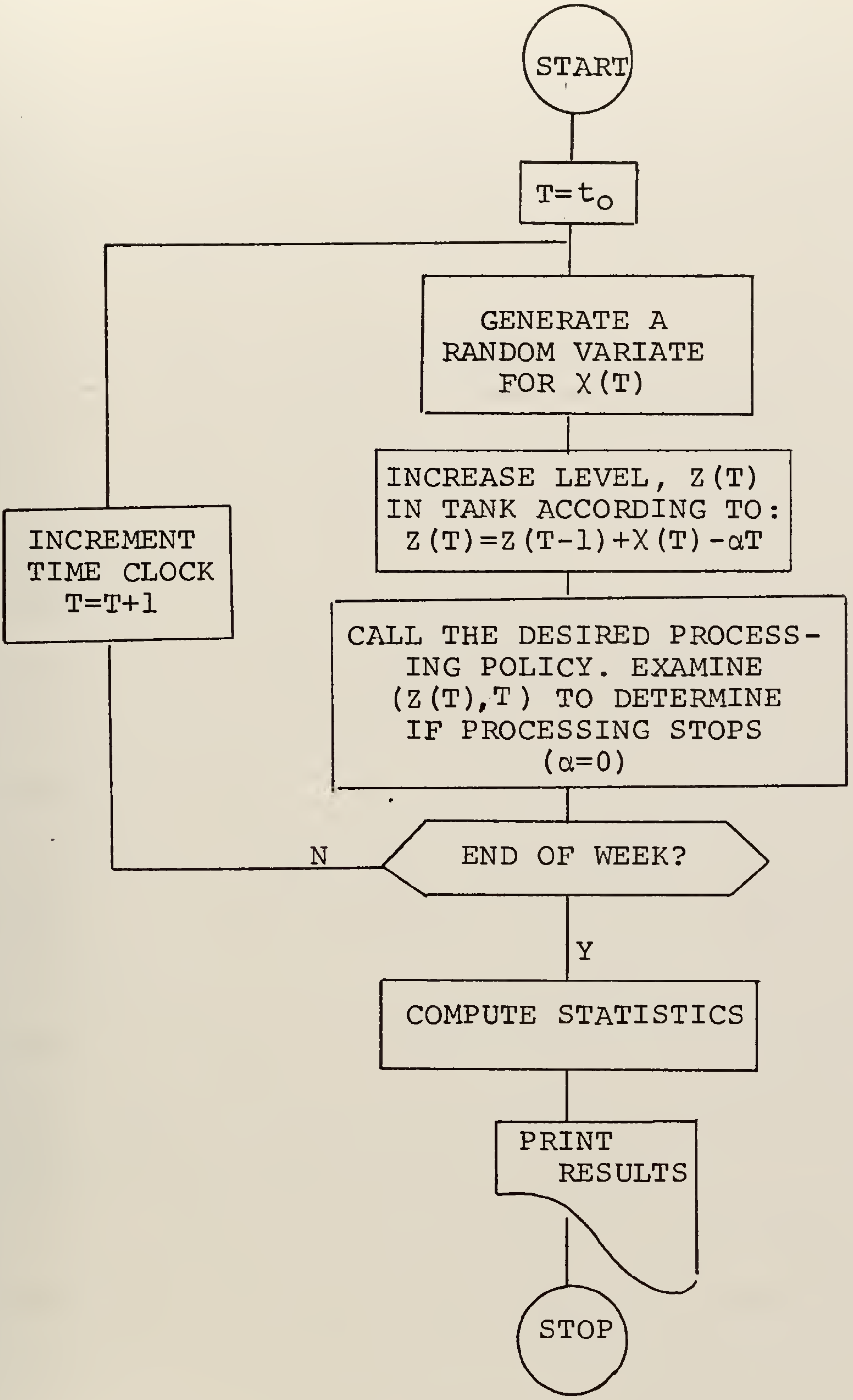

START
$T=t_o$
GENERATE A RANDOM VARIATE FOR $X(T)$
INCREASE LEVEL, $Z(T)$ IN TANK ACCORDING TO: $Z(T)=Z(T-1)+X(T)-\alpha T$
CALL THE DESIRED PROCESSING POLICY. EXAMINE $(Z(T),T)$ TO DETERMINE IF PROCESSING STOPS $(\alpha=0)$
END OF WEEK?
N
INCREMENT TIME CLOCK $T=T+1$
Y
COMPUTE STATISTICS
PRINT RESULTS
STOP

Figure 2. General Flow Chart of the Simulations.

problem. This was done in order to get some idea of what the maximum sewage level (ZMAX) in the tank would be, according to the processing rate and policy used. This further simplified the basic model, so that the only equations needed for the simulation were:

$$Z(t) = \begin{cases} Z(t-1)+X(t)-\alpha t, & \alpha \geq 0 \\ 0 & \text{if } Z(t-1)+X(t)-\alpha t \leq 0 \end{cases} \tag{4}$$

Both simulations involved discrete time steps; for model one, the unit of time was 5 minute increments; for model two, hourly increments. In both cases the total period of time simulated was one week, based on the assumption that it was desirable to have any sewage build-up during the week processed, and the tank emptied by the end of the weekend. A new cycle would then correspond to the start of a new work week. It should be noted that each simulation day started at 0500 real time. At each discrete time increment, a random observation of sewage input, X(t), was generated and the level, Z(t), was computed using equation (4) for a specific processing rate, α.

Anyone of five processing policies, in the form of separate subroutines could be called independently and applied to the model. The following five policies were used:

1) Plan 1. Continuous holding with no processing whatsoever ($\alpha=0$).

2) Plan 2. Continuous processing at some rate, α, to be read in by the programmer.

3) Plan 3. Process continuously from 0500 until 1600 each day; after 1600 stop processing when the tank level reaches 50 gal; continue processing at 0500 the next day. For weekends stop processing anytime the tank level reaches 50 gal; continue processing when the tank level builds up to 500 gal. (This is a combination of a level policy, Plan 4, and a time policy, Plan 5, as described below.

4) Plan 4. (A level control policy) Stop processing whenever the tank level goes below some prescribed limit (50 gallons was used in the simulations - the value is read in by the programmer). Continue processing when the level exceeds an upper limit (1500 gallons was used).

5) Plan 5. (A time control policy) Process continuously for a fixed portion of each day. (For the simulations processing stopped at hour 16, 2100 real time and continued at the beginning of the next simulated day, 0500 real time.)

Policies one and two illustrate the two extremes possible. The policy of continuous holding (Plan 1) was used to determine the amount of sewage that would build up over a certain period of time. (The special case of a twelve hour holding tank was tested using this policy.) The policy of continuous processing (Plan 2) was used to get an indication of the minimum tank levels that could be expected over any range of processing rates desired.

The remaining three policies were developed as examples of probable real world policies. They also served to reflect the response of the simulations to changes in policy, for which the simulations produced acceptable results. Of the three, policy five would be expected to be the least expensive since it simply involves turning the processor off

once a day. Policy four, on the other hand, would require a level sensing device and some sort of automatic start/stop mechanism to the processor and would, therefore, entail a considerably larger cost. Policy three would only require manual operation and its relative cost would fall somewhere in between that of policies four and five. The point to be considered for all three is the fact that the smaller the time required for the processor to operate, the lower the overall running cost and the time available for system maintenance.

It is emphasized that the simulations are in no way limited to just these policies and that any other policy may be tested simply by the addition of a subroutine similar to those used and a statement by which to call it. Further details on the mechanics of using the computer simulations are contained in Appendix D.

2. Input Distribution by Simulation One

One of the most important problems to be solved was how to generate reasonably accurate observation of the arrivals of sewage to the holding tank. The two parameters that had to be considered were 1) the arrival rate and 2) the quantity of sewage per arrival. Although a study was conducted in 1964 [Ref. 19] to determine the quantity of sewage generated per man per day on a Naval vessel, no definitive statistics were obtained to describe the arrival process over the course of a 24 hour period. Owing to the nature of shipboard routine, which can be considered

reasonably standard throughout the Navy, it was evident that the arrival distribution would be multimodal over the period of the day. With such changes in arrival rates it was also clear that the process could not be considered stationary for a 24 hour period and that some form of non-homogeneous process would be required.

In a related study by Gephart and Balachandran [Ref. 9] into the reliability considerations of an airborne sewage system for large jet liners, data was collected on the arrival behavior of passengers to the restroom facilities. It was concluded by the authors that the arrival process could be considered Poisson over "non-overlapping and consecutive time segments." It appeared reasonable, then, that a non-homogeneous Poisson process could also be applied to the sewage generation problem on board a Naval ship.

In its most general form, the process could also be considered a compound Poisson process represented by

$$X(t) = \sum_{i=1}^{N(t)} Y_i \qquad (5)$$

where $\{N(t), t \geq 0\}$ is Poisson process and $\{Y_n, n=1,2...\}$ is a family of independent, identically distributed random variables representing the quantity of sewage per arrival. If a distribution for the body waste generated per capita per arrival were known, this could easily be incorporated into the simulation. For the purpose of simplicity,

however, the quantity of sewage per arrival was taken to be a constant and the compound property was disregarded. Based on studies [Ref. 19] which determined the quantity of water per flush to be 4.5 gallons, a rather conservative estimate of 4.9 gallons per arrival was used.

The final problem, then, was to determine the best estimate of the arrival behavior at head facilities over a 24 hour period. It was decided that the day could logically be partitioned into three periods: the first being the period between 0500 and 1600 when the majority of the crew is on board for the working day; the second being the period between "liberty call" and "taps" (1600-2200) and the last including the time from 2200 until 0500. The intensity function $\lambda(t)$ which describes the arrival rates could then be written for weekday periods as:

$$\lambda(s) = \begin{cases} \lambda_1, & 0 \leq s \leq t_1 \\ \lambda_2, & t_1 < s \leq t_2 \\ \lambda_3, & t_2 < s \leq t \end{cases} \tag{6}$$

and assuming that the majority of the crew is on liberty over the weekend, then a reasonable intensity function for weekends might be

$$\lambda(s') = \begin{cases} \lambda_2, & 0 \leq s \leq t_1' \\ \lambda_3, & t_1' < s \leq t \end{cases} \tag{7}$$

where λ_1 and λ_3 are identical for both sets of equations.

Thus the mean value function is:

$$m(t) = \int_0^t \lambda(s)ds = \lambda_1 t_1 + \lambda_2 (t_2 - t_1) + \lambda_3 (t - t_2) \tag{8}$$

and

$$m(t') = \int_0^t \lambda(s')ds = \lambda_2 t_1' + \lambda_3 (t - t_1') \qquad (9)$$

and it can be shown that

$$P\{N(t)=n\} = \frac{e^{-m(t)} [m(t)]^n}{n!} \quad , \quad n>0 \qquad (10)$$

This then describes a non-homogeneous Poisson process. The values for each λ_i were determined by comparing the mean value function m(t), multiplied by 4.9 gallons of sewage/arrival, to the expected daily and weekly sewage build-up. The details of this are contained in Appendix A. The final values used for each λ_i are presented in Figure 3.

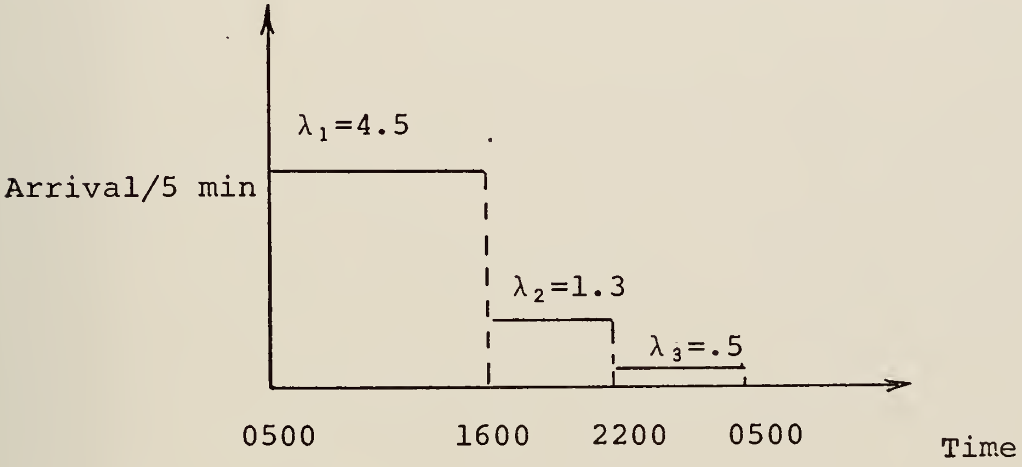


Figure 3. Arrival Rates for Simulation One.

The simulation involved generating Poisson variates for each 5 minute increments of simulated time, using the above parameters during the periods indicated. The number of arrivals was then converted to a quantity of sewage X(t) according to:

$$X(t) = N(t) \times 4.9 \text{ gal/arrival} \tag{11}$$

giving the necessary random input for $X(t)$ which is then applied to the basic model as described in section 1 above.

3. Input Distribution as Described by Simulation Two

Although the reasoning behind Simulation One was considered sound, it was decided that a second simulation could be developed through a different approach. Not only would it take full advantage of all known data, but it would provide an experiment by which the two simulations could be weighed against one another.

In order to get the best approximation to the true arrival distribution over a 24 hour period on board ship, a group of experienced Naval personnel were surveyed for their estimates of the actual arrival pattern (i.e. hydraulic loading) of water closets and urinals over a 24 hour period. From such a survey, an empirical distribution was developed by employing a technique similar to that used to get job time estimates for PERT programming (Program Evaluation and Review Technique). The details of this method of estimation and how it was used are contained in Appendix B. The results are shown in Figure 4a.

Figure 4b gives a similar hydraulic loading pattern derived for a commercial cargo ship with a 40 man crew [Ref. 13, p. 58]. Although the routine on a commercial cargo vessel is considerably different from that on a military vessel, it can be noted that "peak loadings are

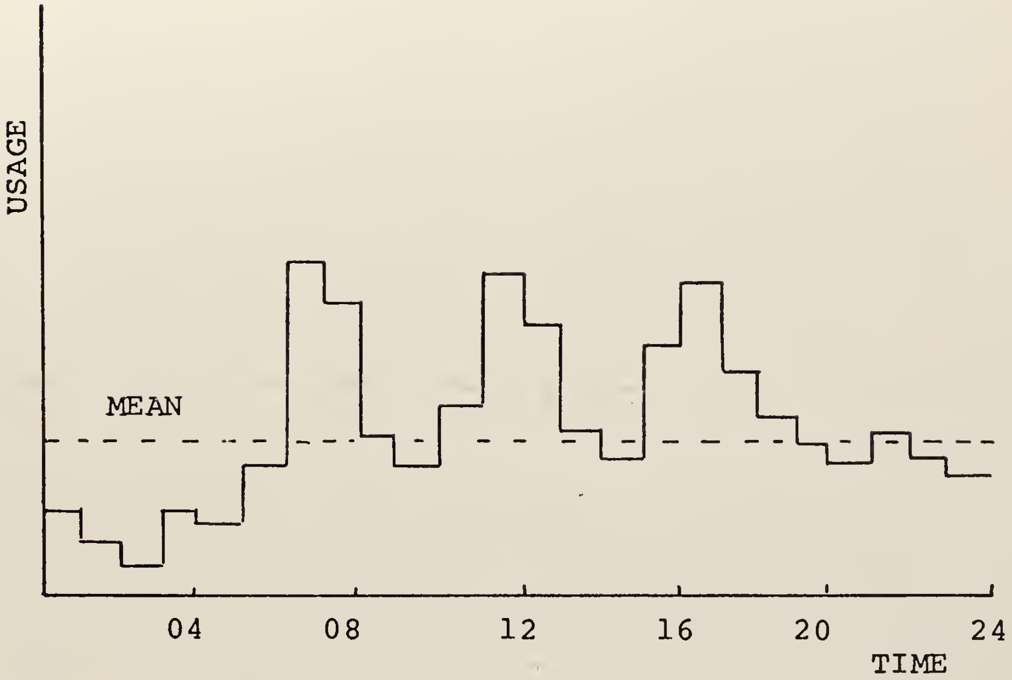


Figure 4a. Estimation of Distribution of Sewage Flow Aboard a Naval Ship.

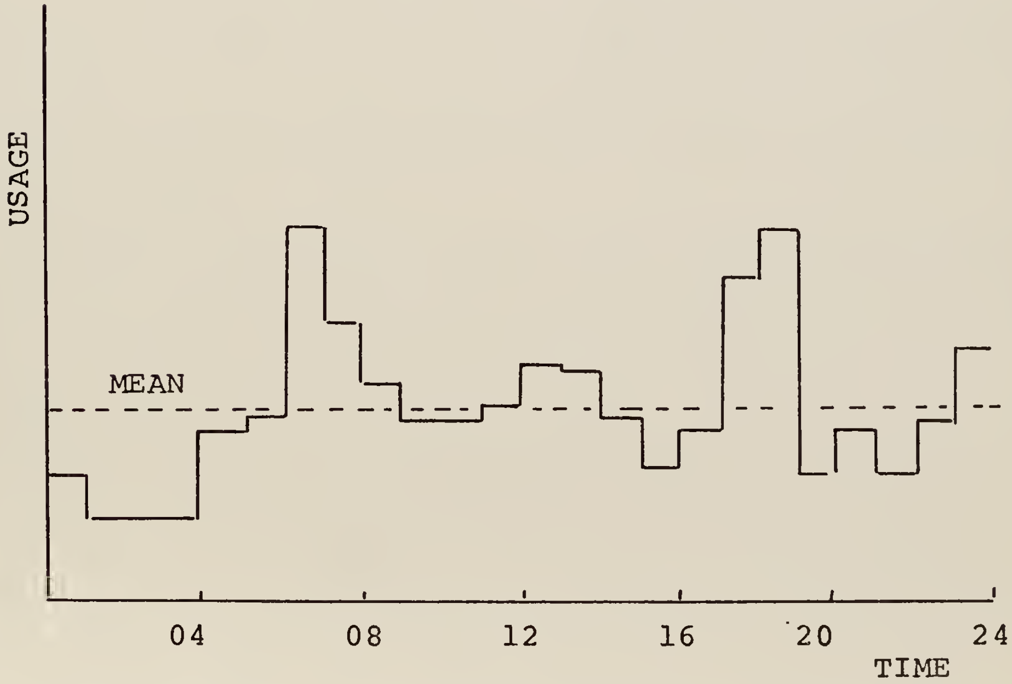


Figure 4b. Distribution of Sewage Flow Aboard a Cargo Ship.

double the average loading and almost five times the minimum loading" for both distributions, and that, in general, they compare favorably.

Once this distribution was established, it was necessary to convert it to realistic quantities of sewage per hour. Again, the hydraulic shipboard data obtained in MEL Report 346/64 [Ref. 19] (which is the basis of current Navy design parameters of 30 g.m.p.d.) was used to estimate a distribution of the daily per capita sewage flow. This data, however, was revised in a thesis by D. B. Campbell (a fact not incorporated in design specifications listed in Ref. 2, p. E-1). Combining both sets of information it was decided that daily per capita sewage flow rates could best be represented by a beta distribution with a most likely (mode) value of 14.8 gal/man/day, a maximum of 20.0 g.m.p.d. and a minimum of 11.3. As shown in Appendix C, these values were used to estimate the parameters of a beta distribution [Ref. 17, p. 196].

Observations of the daily sewage generation rate per man were then generated from this beta distribution for each day of the simulated week. Once a daily average was generated it was converted to an hourly average for a ship with 240 men. (The number of men was arbitrary and could be read in by the programmer.) Finally, it was translated to the empirical distribution by conversion ratios of the hourly relative value to the relative mean. For example at 1200, if the beta realization was 15 gal/man/day then:

$$\text{Hourly Realization} = \frac{\text{Relative Value}}{\text{Relative Mean}} \times \frac{\text{Daily Beta Variate}}{24} \times \text{No. of Men} \qquad (12)$$

$$\text{Realization} = \frac{11.3}{7.3} \times \frac{15}{24} \times 240 = 232 \text{ gal}$$

Such values were the hourly realizations of $X(t)$ used as the input to the basic model described in subsection 1.

IV. RESULTS

The results of simulations one and two are presented on pages 32 through 35. Figure 5a and 6a are graphs of the average maximum level of sewage held as a function of processing rate for the five policies tested by simulations one and two respectively. Figures 5b and 6b represent the average total time the processor must run in a week's period (of a possible 168 hour maximum), again as a function of processing rate for each of the five policies. The results agree well with intuition.

Looking first at the results common to both simulations, one observes that the maximum average sewage level has an inverse relationship to the processing rate. The percent savings in tank size decreases with higher processing rates, and, for rates greater than 210 gal/hr, the savings appear to be negligible. For policies in which processing time can vary, the total weekly processing time is also inversely proportional to the processing rate, and, over the range of rates considered, the function is nearly linear.

The different policies considered have a significant effect on sewage level and processing time. Policy two describes a limit on minimum sewage level obtainable for the rates considered. The curve of maximum sewage level increases with each higher policy number up to policy five. Conversely, for average processing time the trend is just the opposite as was expected. Policy two requires the

maximum processing time and each succeeding policy number requires less. For the policy of strictly holding sewage (policy 1), the average sewage accumulated in a week's period (assuming the ship to be a destroyer with a complement of 240 men) was 21,100 gallons, with a variance of 8.2×10^4 gallons^2 for simulation one, and 21,080 gallons with a variance of 23.4×10^5 gallons^2 for simulation two. The average values for a 12 hour holding period were 3,057 gallons for simulation one and 2,700 gallons for simulation two.

Certain additional observations could be made that were peculiar only to simulation one. First, a definite change in the slope of the curve for maximum tank level vs processing rate occurs at 150 gal/hr, with little additional savings in tank size being realized beyond that. For processing rates above 150 gal/hr, the average maximum tank level was never above 2,500 gallons. The variance/mean ratio for maximum tank level is on the order of from 2 to 10. It is usually highest for a processing rate of 140 gal/hr, and drops off immediately thereafter. For policy four the ratio is much lower than for other policies. For processing time vs processing rate the variance/mean ratio is on the order of 10^{-2}, and policies 3 and 4 show little appreciable difference in time savings.

For simulation two, it can be seen that, with policy two as a reference, the curve of maximum level vs processing rate levels off more rapidly for policies 3 and 4 beginning

at approximately 160 gallon/hr. The curves for policies 3 and 4 follow the same contour with policy 3 having a maximum sewage level on the order of 1000 gallons less than policy four for all rates. The variance/mean ratio for maximum sewage level is on the order of 10^2 to 10^3 at 140 gal/hr and decreases as processing rate increases. At higher processing rates the ratio is significantly less for policy four (approx. 20) than for other policies. For processing time vs processing rate, policies three and four have the same slope, with policy four showing only a slight savings in time of about 5 hrs for the week. The variance/mean ratio for either policy is again very small, on the order of 0.5.

A comparison of the two simulations reveals that, although the average results of simulation one are on the same order as those of simulation two, the variance of the results is much smaller for the former. This is not suprising, since simulation one is based on the Poisson process in which the variance of the asymptoptic distribution of N(t) will equal the mean. In the case of a non-homogeneous process in which the parameters do not differ greatly, it can also be expected that as the number of replicates increases the sample variance will approach some value on the same order of magnitude as the mean. For simulation two, the realizations of the daily average sewage rate per man can vary from 11.3 gal/man/day to 20.0 gal/man/day which is

then imposed on an empirical distribution with even greater variance. The result is a process with reasonably large variance; certainly much greater than that resulting from simulation one.

Figure 5a. Maximum Tank Level vs Processing Rate for Simulation One.

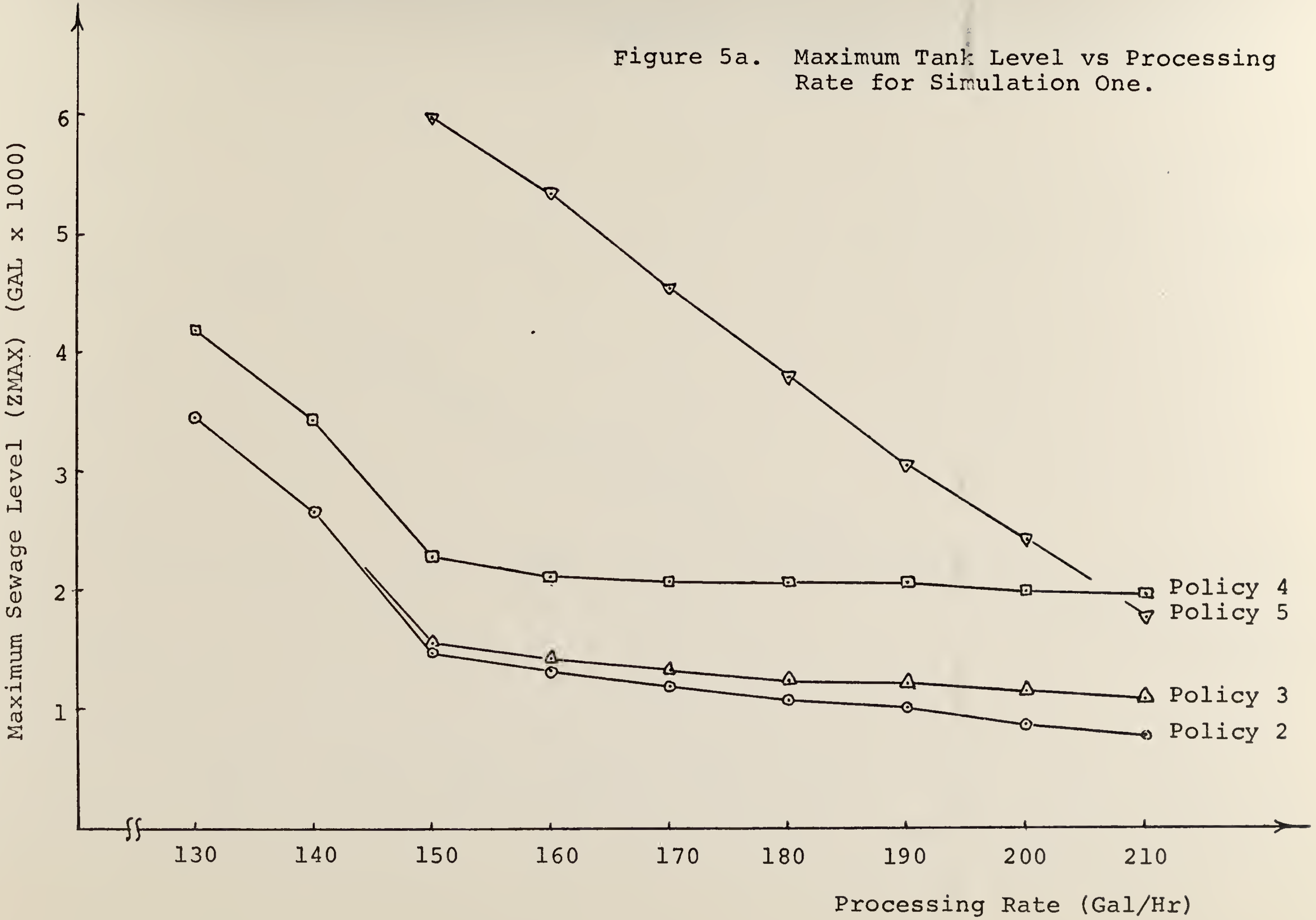


Figure 5b. Average Processing Time vs Processing Rate for Simulation One.

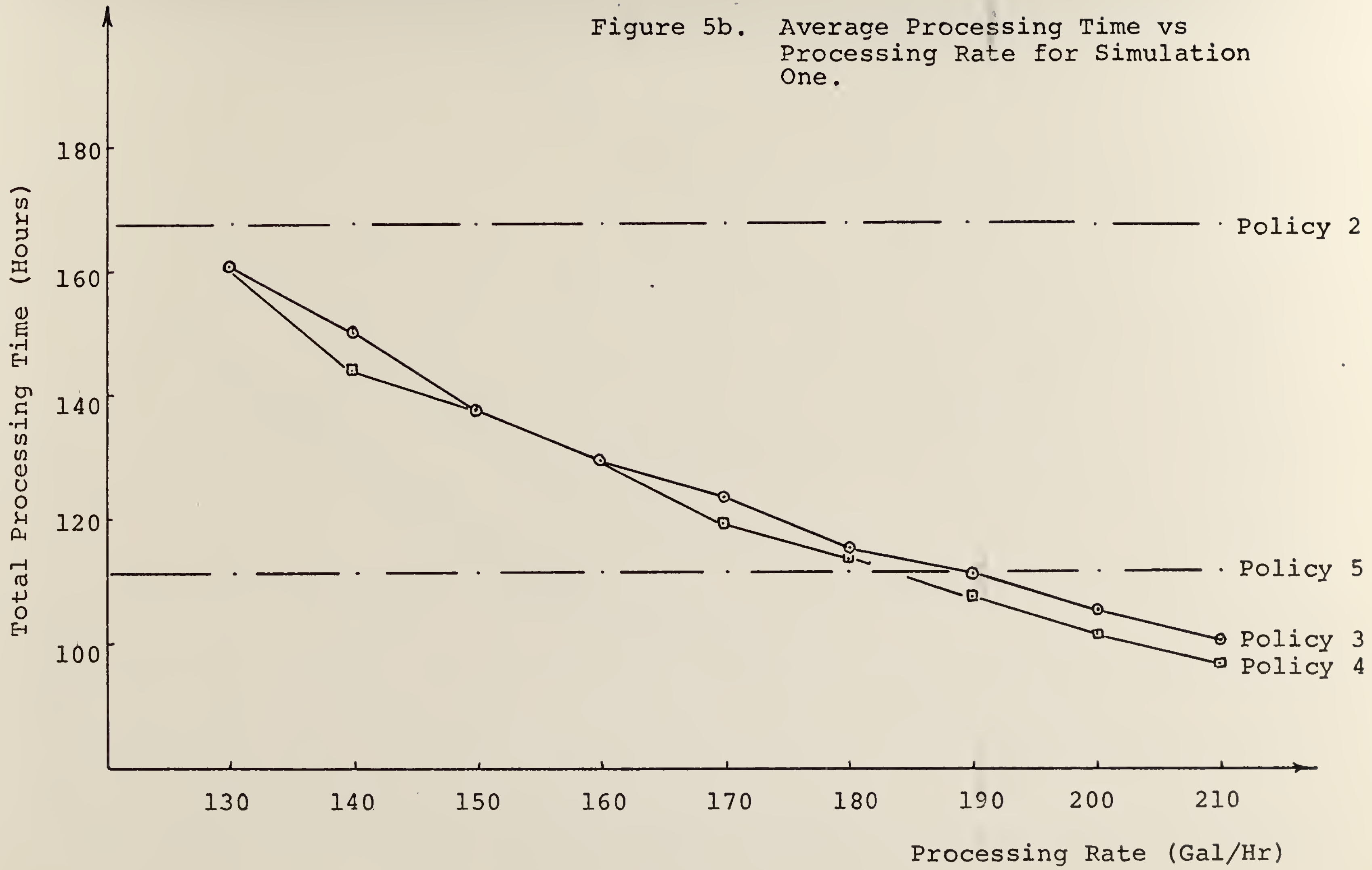
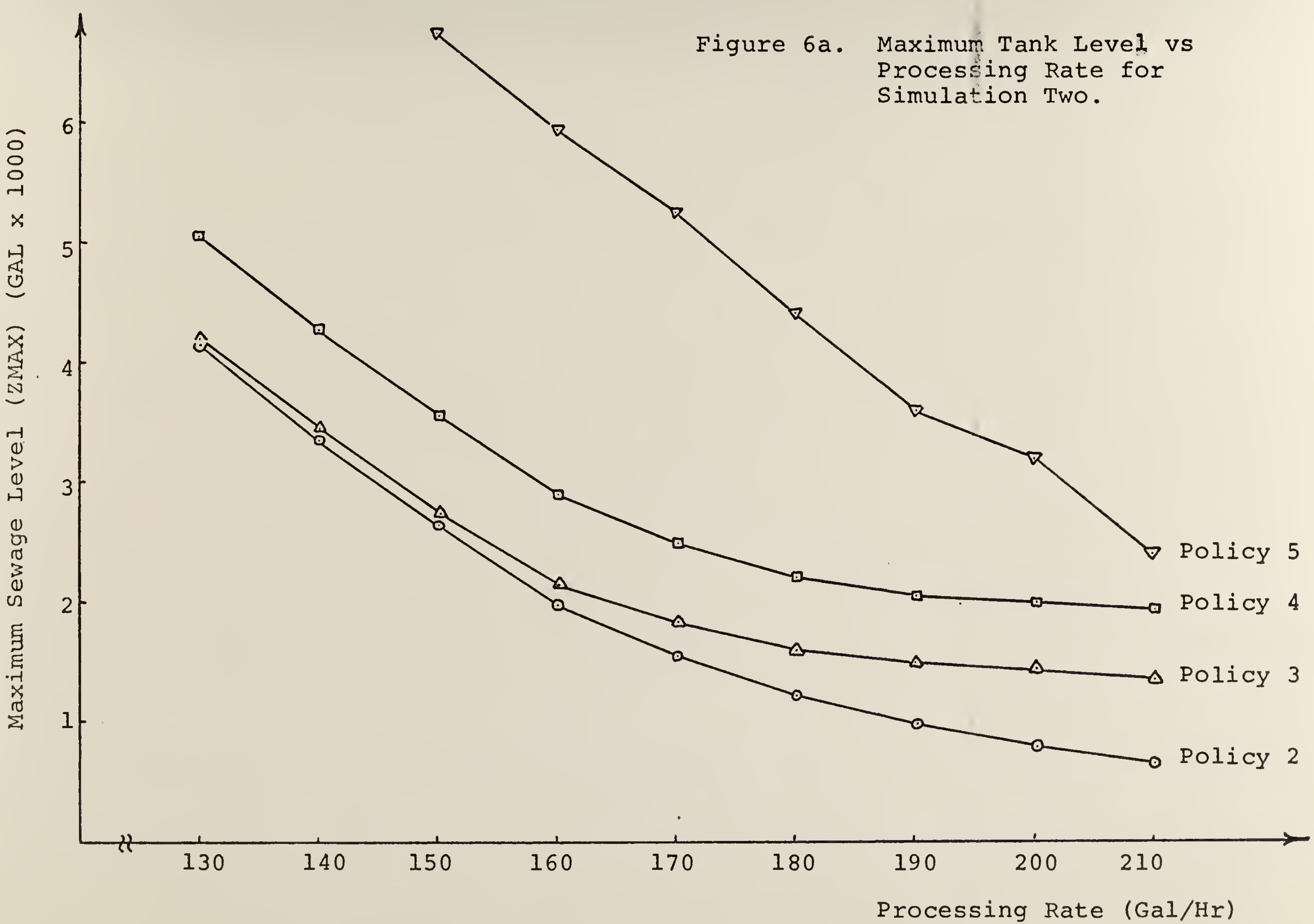


Figure 6a. Maximum Tank Level vs Processing Rate for Simulation Two.



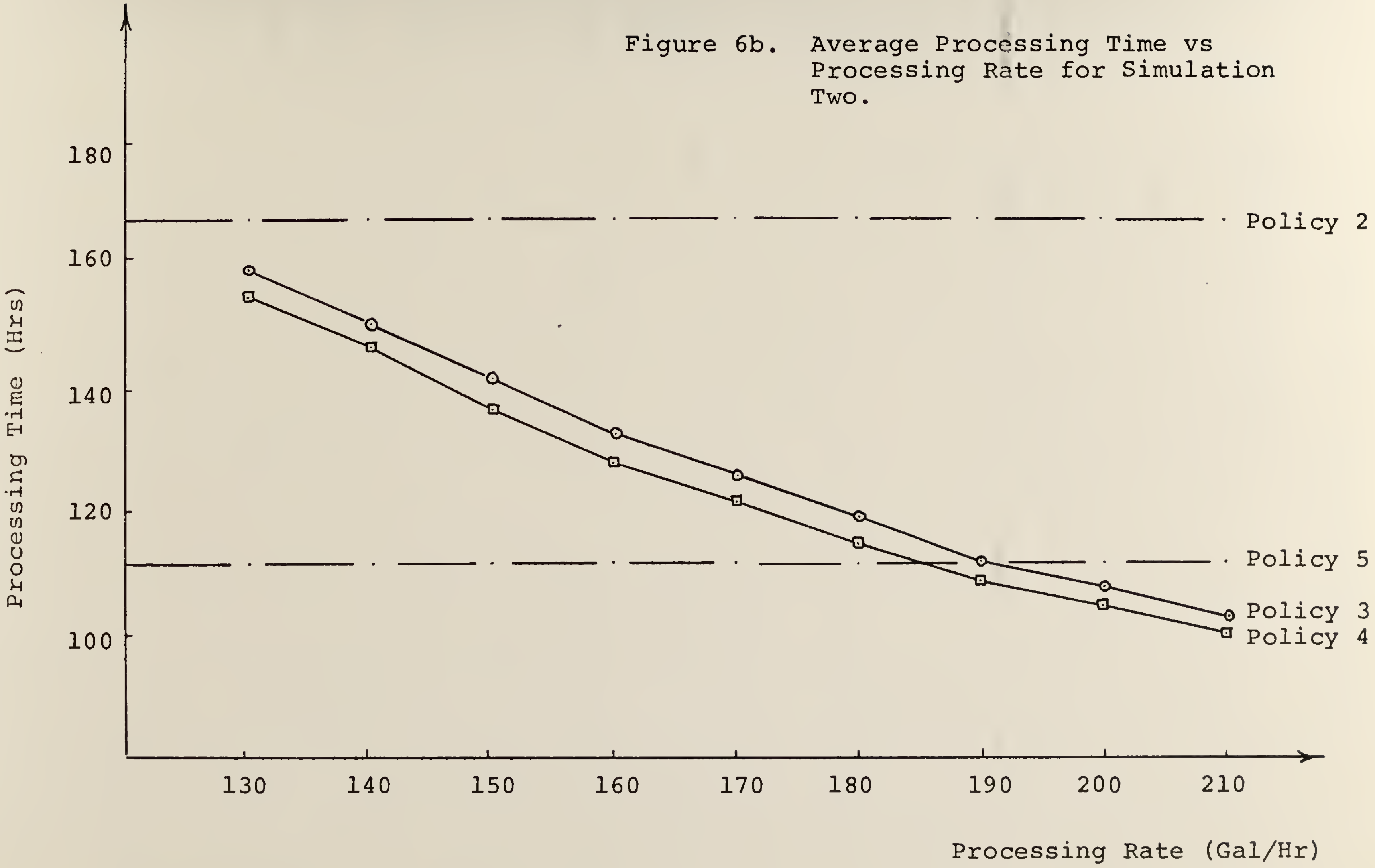


Figure 6b. Average Processing Time vs Processing Rate for Simulation Two.

V. CONCLUSIONS AND RECOMMENDATIONS

A. INTERPRETATION OF RESULTS

In order to prescribe the most feasible combination of processing rates, policies and holding tank size, more information regarding the cost function of each particular parameter would have to be developed. If costs were assumed to follow some increasing linear function of processing rate, holding tank size and processing time, then the policy and rate which would minimize a measure of effectiveness taking all such costs into account would be expected to be most feasible.

Based on the results of Chapter IV and with the understanding that cost functions must be applied, it appears that a system consisting of a holding tank of 2,700 gallon capacity for sewage combined with a processing unit capable of handling 160 to 170 gallons of sewage per hour would be most beneficial. Further such a system should be operated under a processing policy similar to that of policy 3.

It was contended in Chapter I that the Navy's design parameter of 30 gallons/man/day was over estimated. The simulations, which were developed using the best data that could be obtained, bear out this conclusion. More specifically, if this current value were used to construct a 12 hour holding tank for a destroyer of 240 men, the minimum tank size would be 3600 gallons. The values obtained through simulation, which were measured during the period

when traffic flow was the greatest (0500 to 1700), were, again, 3,050 gallons for simulation one, and 2,700 gallons for simulation two. Even with the addition of a 200 gallon safety factor, it appears evident that a savings of between 400 to 700 gallons could be realized for each 12 hour holding tank installed. Even greater savings would be expected for larger tanks.

The capacity of a holding tank based on the quantity of diluent (flushing liquid) used can also be computed using an equation presented in a report by the Maritime Research Information Service [Ref. 13]. Namely:

$$C = 1.25 \times M \times (B+D) \qquad (13)$$

where

C = tank capacity
M = man days of storage
B = daily per capita body waste = 0.437 gallons
D = diluent in gallons/man/day.

If the value of diluent is taken to be 15 gal/man/day, the unmodified mean of the data obtained by MEL Report 346/64, then the recommended holding tank size would be 2,320 gallons. The values obtained by simulation would thus appear conservative; however, it is important to realize that they also account for peak arrival periods.

B. RECOMMENDATIONS

The simulations described in this thesis offer sufficient merit for use in the design of sewage treatment systems. It is recommended that a study be made to obtain further

statistics on the arrival pattern of head facilities aboard a Naval ship. Such new data could then replace the empirical distribution developed for simulation two, or be used to revise the intensity function of simulation one. This should lead to even more meaningful results than those presented.

It is further recommended that design parameter for daily per capita sewage generation be reviewed. If it is decided that it is in fact overestimated, then it is recommended that 12 hour holding tanks of the size presented in this report be tested on board destroyer-sized ships, and that the simulations be employed to develop holding tanks for larger ships as well.

APPENDIX A

CALCULATION OF ARRIVAL PARAMETERS

As pointed out in the body of the thesis, the mean value function was used to estimate the best values of λ_i ($i=1,2,3$). This was done by computing average daily and weekly sewage generation first by using the average values presented in MEL Report 346/64 [Ref. 19], and second by use of policy one and simulation two. The values obtained from weekly observations of sewage build-up as estimated by simulation two were used since 1) they were considered more representive and 2) they would also serve as a means of normalizing both simulations so that over long periods of time the two simulations would give similar results for strict holding. Average daily and weekly sewage generation was then divided by 4.9 gal/arrival to determine the number of arrivals/period.

The results were:

Weekly average = 21,000 gal/week/4.9 gal/arrival

= 4260 arrivals/week

similarly:

daily average = 730 arrivals/day.

These were then equated to the mean value function which was

$$M(t) = 5(m(t)) + 2\ (m(t')) = 5[\lambda_1(t_1)+\lambda_2(t_2-t_1)+\lambda_3(t-t_2)] + 2[\lambda_2(t_1')+\lambda_3(t-t_1')] \qquad \text{(A-1)}$$

for the weekly value, and

$$m(t) = \lambda_1(t_1)+\lambda_2(t_2-t_1)+\lambda_3(t-t_2) \qquad \text{(A-2)}$$

for the daily value.

Substituting in the values for t_i where $t = 24$ hours = 288 five minute increments and setting them equal to the weekly and daily sewage build-ups, one gets:

$$\text{weekly:} \quad 660\lambda_1 + 768\lambda_2 + 588\lambda_3 = 4260 \qquad \text{(A-3)}$$

$$\text{daily:} \quad 132\lambda_1 + 72\lambda_2 + 84\lambda_3 = 730 \qquad \text{(A-4)}$$

where: $t_1 = 132$, $t_2 = 204$, $t = 288$, $t_1' = 132$.

In order to solve the above simultaneous equations a third equation was needed. This was obtained from weekends and computing a third average build-up for that period to obtain:

$$2\ m(t') = 2{,}100/4.9 = 420 \text{ arrivals/weekend}$$

or

$$264\lambda_2 + 312\lambda_3 = 420. \qquad \text{(A-5)}$$

Solving (A-3) through (A-5) simultaneously one obtains the final estimates of λ_i $(i = 1,2,3)$ namely:

$$\hat{\lambda}_1 = 4.5 \text{ arrivals/5 min}$$
$$\hat{\lambda}_2 = 1.0 \text{ arrivals/5 min}$$
$$\hat{\lambda}_3 = .5 \text{ arrivals/5 min}$$

which agree well with intuition.

APPENDIX B

METHOD OF ESTIMATION FOR AN EMPIRICAL DISTRIBUTION

In order to obtain the hydraulic loading pattern of water closets and urinals aboard Naval ships, it was necessary to resort to a subjective estimation technique. The technique used is the same as that for obtaining job time estimates for PERT scheduling computations [Ref. 14]. Such a technique is employed when one is unable to do any statistical sampling.

It was, therefore, decided to survey a cross-section of experienced Naval personnel, both officers and enlisted, for their subjective estimates of the relative usage of head facilities for each hour of a 24 hour period. Their estimates were made on a relative scale of 0 to 20, (0 indicating the facility was not used at all, 20 indicating it was used to capacity). Each person was to give a high, most likely, and low estimate, independent of estimates made by others.

It has been "historically accepted" that job duration times described by such estimates are beta distributed over a finite interval given by the high and low estimate. The same distribtuion can be assumed to apply to estimates of the arrival pattern. The expected value of such a distribution can then be approximated by:

$$U_e = (a+4m+b)/6 \qquad \text{(B-1)}$$

and the variance by;

$$V_a = [(b-a)/6]^2 \tag{B-2}$$

where:

a = low (optimistic) estimate

m = most likely (mode) estimate

b = high (pessimistic) estimate.

Using the expected value, U_e, as the best estimate of each individual. All such values were then averaged to give the overall best estimate for each hour of the 24 hour period. The results are the empirical distribution plotted in the body of the thesis (Figure 4a).

APPENDIX C

ESTIMATION OF BETA PARAMETERS

A beta distribution that is transformed to some interval other than (0,1) is given by:

$$f(T) = \begin{cases} \dfrac{\Gamma(A+B)}{\Gamma(A)\Gamma(B)} (b-a)^{1-A-B} (T-a)^{A-1} (b-T)^{B-1}, & b \geq T \geq a \\ 0 & \text{elsewhere} \end{cases} \qquad (C-1)$$

where T is the transformed beta variable given by:

$$T = a+(b-a)\chi \qquad (C-2)$$

χ being a (0,1) beta variable and a,b being the lower and upper bound of the transformed variable. If the high (b), low (a) and most likely (m) values of the distribution can be determined, then the transformed beta parameters can be related to (0,1) beta parameters according to:

$$A = 46E(\chi) \; [E(\chi)-E(\chi)^2 - \frac{1}{36}] \qquad (C-3)$$

$$B = \frac{A-AE(\chi)}{E(\chi)} \qquad (C-4)$$

where

$$E(\chi) = \frac{4m+b-5a}{6(b-a)} \qquad (C-5)$$

Using the values obtained from MEL Report 346/64 i.e.:

a = 11.3 gal/man/day
m = 14.8 gal/man/day
b = 20.0 gal/man day.

Then the values for the parameters can be solved for, using the above equations to obtain:

$A = 4.3 \qquad B = 5.7$

These values are then used to generate a beta variable, X, by first generating two independent gamma variates $Y_1 \sim G(1,A)$ and $Y_2(1,B)$ and computing the ratio

$$X = \frac{Y_1}{Y_1+Y_2} \qquad \text{(C-6)}$$

It then remains only to transform X to a realization of T using equation (C-2).

APPENDIX D

USE OF SIMULATION ONE AND TWO

The two simulations were programmed in Fortran IV for use on the IBM 360/67 computer. Both simulations allow the option of plotting the graph of the sewage build-up (inventory) for each hour of the week. (Examples of such plots are given under computer output.) If one uses the option, however, he must insure that the appropriate JCL cards are used for his particular hardware.

Only one data card is needed for either simulation. All that must be provided are the parameters to be tested, an indication of print routine to be used and a flag for calling the plot routine. For each simulation the format of the data card is as follows:

a) Simulation One. The following variables must be supplied:

Variable	Cols on Card	Description
Plan 1	0-5	As described in the body of the thesis, these are the arrival rates/5 min that are used for the Poisson generator.
Plan 2	6-10	
Plan 3	11-15	
Alpha 1	16-18	The initial processing rate seed, in gal/5 min processed. It is increased by 10 gal/hr as soon as it is read in.
NPLAN	19-20	A two digit integer specifying the processing plan to be tested.

NOPRIN	21-22	A two digit integer to indicate which of four print routines is to be used. (See below for discription of these routines.)
NO DRAW	23-24	A flag to indicate if plot routine is desired (any 2 digit number) or not (use zero).
ZSTOP,ZSTART	25-20 30-34	These are the level parameters for policy 4 in F5.1 format.
TSTOP	34-36	A 3 digit integer representing the stopping time for policy 5.

For simulation two the same values are read in with the exception of the Poisson parameters, instead the number of men representing the size of ship is read in as a 3 digit integer.

For the print routines it should be noted that if full printout is used that this can add considerably to the running time of the program. Depending on the read in for NOPRIN, the routines are:

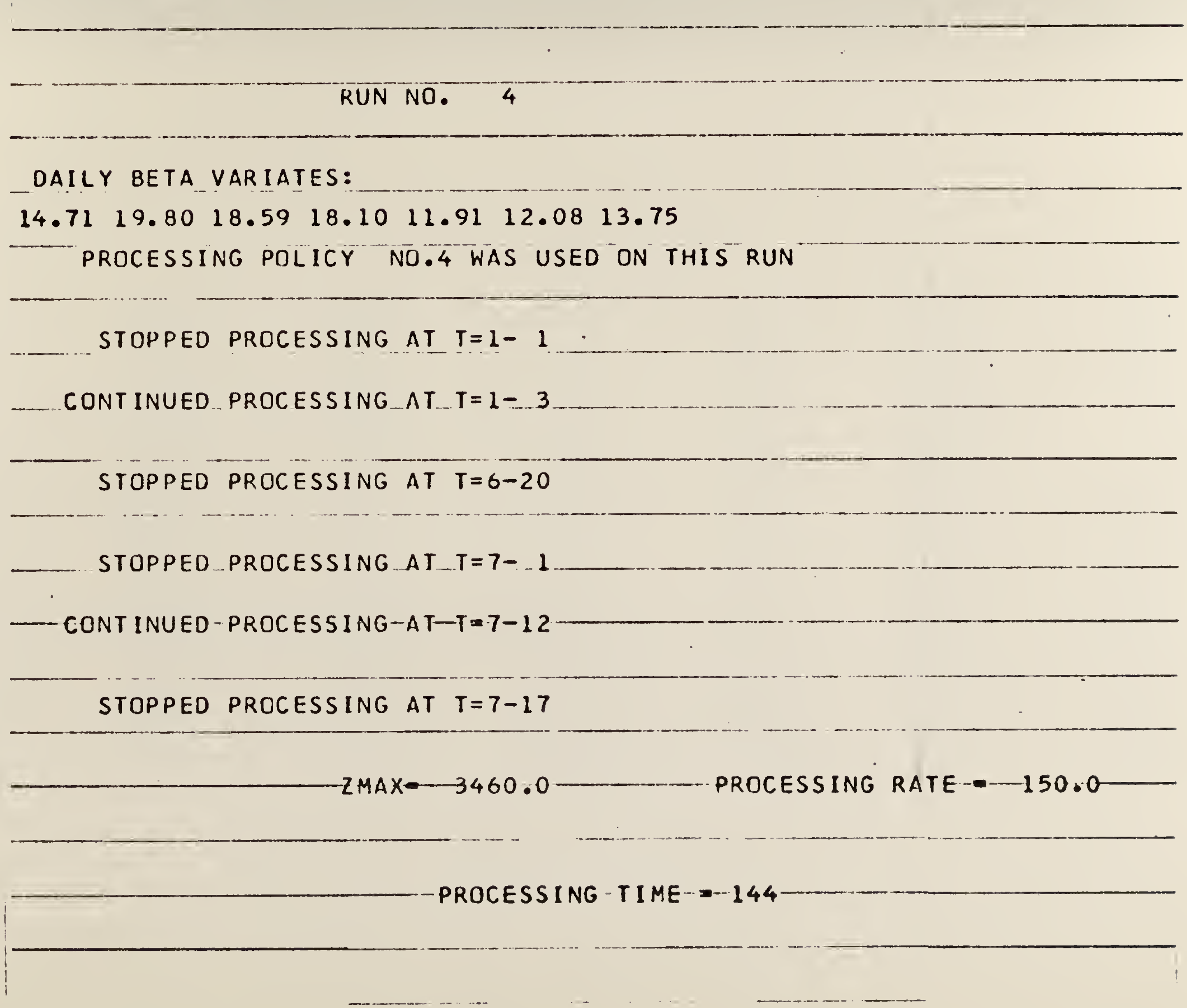
NOPRIN	ROUTINE
1	Print only the final statistics for ZMAX matrix and the processing time matrix.
2	Print above plus the times that the processor stop and restarted during the week. Print also the processing rate, run number and maximum tank level on each run.
3	Print the above plus the entire Z(t) matrix (also the X(t) matrix for simulation 2).

4	Print the above plus the X(t) matrix and arrivals matrix. (Simulation One)

In conclusion, it should be pointed out that simulation one requires approximately 2000 random numbers to be generated per replication; it requires considerably more computer time than simulation two. This is inpart compensated for, however, by its smaller variance, so that fewer runs are needed.

COMPUTER OUTPUT

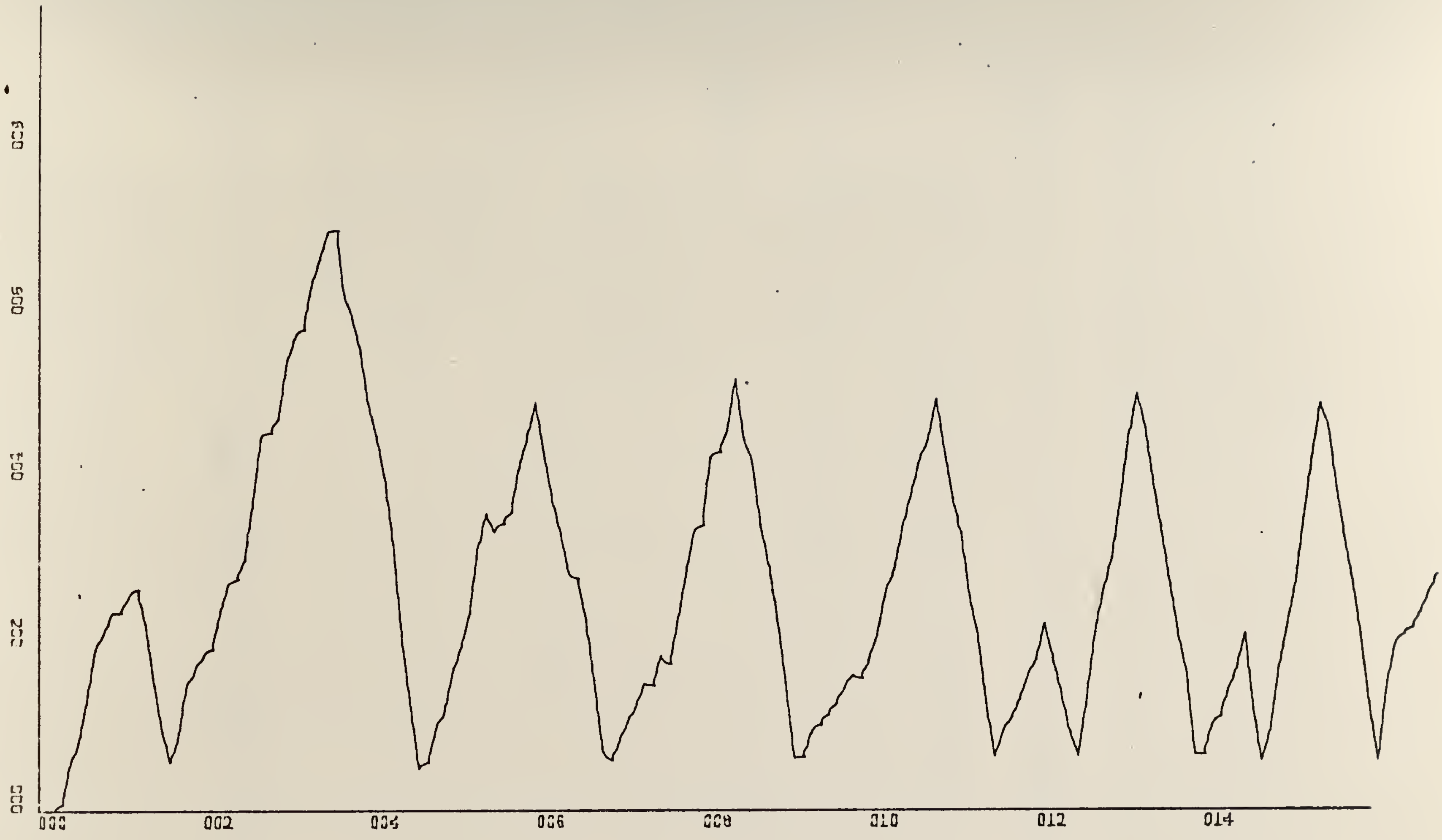
(Sample only)



```
                    RUN NO.    4

DAILY BETA VARIATES:
14.71 19.80 18.59 18.10 11.91 12.08 13.75
    PROCESSING POLICY  NO.4 WAS USED ON THIS RUN

     STOPPED PROCESSING AT T=1- 1

   CONTINUED PROCESSING AT T=1- 3

     STOPPED PROCESSING AT T=6-20

     STOPPED PROCESSING AT T=7- 1

   CONTINUED PROCESSING AT T=7-12

     STOPPED PROCESSING AT T=7-17

                    ZMAX=  3460.0          PROCESSING RATE =  150.0

                           PROCESSING TIME = 144
```

```
Z MATRIX

     0.0      421.8      812.6        0.0      867.7        0.0      837.6
   209.3      632.1      913.1       76.6      961.1       84.0      726.6
   389.0      812.7      992.3      133.7     1033.8      161.7      610.4
   399.4      823.5      949.4       79.2      987.4      202.7      464.2
   379.8      804.3      885.1        5.0      920.1      237.4      312.7
   415.3      840.3      860.3        0.0      891.4      293.9      170.9
   591.0     1016.9      936.6       54.5      961.3      350.6       54.0
   729.2     1155.8      995.9       84.2     1094.8      429.3        0.0
   739.5     1166.6      943.0       29.7      958.4      470.4       33.8
   722.6     1150.1      880.5        0.0      893.0      505.6       62.7
   833.1     1261.3      909.8       11.5      917.0      563.3      114.2
   987.1     1416.1      970.4       51.7      971.6      640.4      173.5
  1066.0     1495.6      977.0       42.3      973.4      696.2      219.4
  1091.5     1521.7      945.1      177.8      937.8      740.6      255.9
  1077.4     1507.9      894.5      287.1      874.3      776.4      285.3
  1049.5     1480.4      814.2      387.4      801.1      809.2      312.3
  1043.5     1474.8      759.5      502.0      743.3      846.8      343.1
  1015.6     1447.3      689.1      602.3      670.2      879.6      370.1
   971.4     1403.4      607.0      691.8      585.5      908.9      394.2
   889.2     1321.5      497.5      756.3      474.2      930.0      411.6
   777.2     1209.6      366.4      801.1      342.0      944.7      423.6
   643.5     1076.0      219.8      831.6      194.5      954.7      431.8
   550.4      983.2      102.4      888.9       75.5      973.4      447.3
   452.1      885.0        0.0      942.7        0.0      991.1      461.8
```

```
X MATRIX

  149.41     149.77     107.65      98.48     104.94      32.25      26.51
  389.34     390.28     280.52     256.63     273.45      84.03      69.07
  359.70     360.56     259.16     237.09     252.63      77.63      63.81
  190.32     190.78     137.13     125.45     133.67      41.08      33.76
  160.48     160.37     115.63     105.78     112.71      34.63      28.47
  215.42     215.94     155.21     141.99     151.30      46.49      38.22
  355.74     356.60     256.32     234.49     249.85      76.78      63.11
  318.19     318.96     229.26     209.74     223.48      68.67      56.45
  190.32     190.78     137.13     125.45     133.67      41.08      33.76
  163.05     163.44     117.43     107.47     114.52      35.19      28.93
  290.52     291.23     209.32     191.50     204.05      62.70      51.54
  334.00     334.81     240.65     220.16     234.59      72.09      59.25
  258.90     259.53     186.54     170.65     181.84      55.88      45.93
  205.54     206.04     148.09     135.48     144.36      44.36      36.46
  165.82     166.22     119.47     109.30     116.46      35.79      29.42
  152.18     152.55     109.65     100.31     106.88      32.84      27.00
  173.92     174.34     125.31     114.64     122.15      37.54      30.85
  152.18     152.55     109.65     100.31     106.88      32.84      27.00
  135.78     136.10      97.83      89.50      95.36      29.30      24.09
   97.83      98.07      70.49      64.48      68.71      21.11      17.36
   67.99      68.15      48.98      44.81      47.75      14.67      12.06
   46.25      46.36      33.32      30.48      32.48       9.98       8.20
   86.96      87.17      62.65      57.32      61.08      18.77      15.43
   81.62      81.82      58.81      53.80      57.33      17.62      14.48
```



K-SCALE=2.00E+01 UNITS INCH.
Y-SCALE=2.00E+02 UNITS INCH.
TANKSIM1

COMPUTER PROGRAM

```
*                         TANK SIMULATION ONE                          *
************************************************************************
THIS IS THE FIRST OF TWO SIMULATIONS DEVELOPED BY J.O.MINER,
JR. TO DESCRIBE THE PROCESS OF GENERATING AND TREATING
SEWAGE ON BOARD NAVAL SHIPS. IT EMPLOYS A NON-HOMOGENEOUS
POISSON PROCESS TO DESRIBE THE ARRIVAL OF SEWAGE TO A HOLD-
ING TANK OVER THE COURSE OF THE DAY. IT THEN TESTS FIVE PRO-
CESSING POLICIES FOR ANY PROCESSING RATE DESIRED. THE SIZE
OF THE SHIP IS ARBITRARY AND IS READ IN BY THE PROGRAMMER.
************************************************************************
*                                                                      *
*                                                                      *
THE FOLLOWING STATEMENTS INITIALIZE THE PROGRAM AND READ IN
THE VARIOUS PARAMETERS TO BE TESTED,INCLUDING THE PARAMETERS
FOR THE POISSON DISTRIBUTION
*                                                                      *
      COMMON I,J,ITIME,NOPRIN
      DIMENSION Z(7,288),X(7,288),NUM(7,288)
      DIMENSION XORD(168),YORD(168),ZMAX(10,20),TPROSS(10,20
      REAL*8 TITLE(12)/'TANKSIM1',11*'        '/
      REAL LABEL/'    '/
      INTEGER TSTOP
      READ(5,100) PLAM1,PLAM2,PLAM3,ALPHA1,NPLAN,NOPRIN,
     CNODRAW,ZSTOP,ZSTART,TSTOP
  100 FORMAT(3F5.3,F3.1,3I2,2F5.1,I3)
      IX=4321571
*                                                                      *
RUNS ARE MADE FOR NINE PROCESSING RATE IN INCREMENTS OF 10
GALLON/HOUR
*                                                                      *
      DO 6000 M=1,9
      ALPHA1=ALPHA1+.833
      DO 5000 L=1,10
      IF(NOPRIN.LT.2) GO TO 155
      WRITE(6,150)L
  150 FORMAT('1',20X,'RUN NO.  ',I2,//)
*                                                                      *
VARIOUS ARRAYS ARE ZEROED FOR EACH RUN
*                                                                      *
  155 ZMAX(M,L)=0.0
      ALPHA=0.0
      ITIME=0
      DO 30 I=1,7
      DO 20 J=1,288
      Z(I,J)=0.0
      X(I,J) = 0.0
      NUM(I,J) = 0
   20 CONTINUE
   30 CONTINUE
      IX =  IX + 342
*                                                                      *
A POISSON ARRIVAL IS THEN GENERATED FOR EACH FIVE MINUTE
INCREMENT OF THE SIMULATED WEEK. DIFFERENT PARAMETERS ARE
USED ACCORDING TO THE TIME OF DAY OR WEEK.
*                                                                      *
      DO 600 I=1,5
      PLAM = PLAM1
      DO 500 K=1,132
      CALL POISSN(PLAM,IX,N)
  500 NUM(I,K)=N
      PLAM =PLAM2
      DO 510 K=133,204
      CALL POISSN(PLAM,IX,N)
  510 NUM(I,K)=N
```

```
      PLAM = PLAM3
      DO 520 K=205,288
      CALL PO1SSN(PLAM,IX,N)
  520 NUM(I,K)=N
  600 CONTINUE
      DO 750 I=6,7
      PLAM= PLAM2
      DO 700 K=1,204
      CALL PO1SSN(PLAM,IX,N)
  700 NUM(I,K)=N
      PLAM=PLAM3
      DO 720 K=205,288
      CALL PO1SSN(PLAM,IX,N)
  720 NUM(I,K)=N
  750 CONTINUE
      DO 1500 I=1,7
*                                                                  *
THE ARRIVALS ARE THEN CONVERTED TO A QUANTITY OF SEWAGE AND
THE SEWAGE PROCESSED IN ACCORDANCE WITH ONE OF THE FIVE POL-
ICIES.
*                                                                  *
      IF((NPLAN.EQ.1).OR.(NPLAN.EQ.4)) GO TO 90
      ALPHA=ALPHA1
   90 DO 1000 J=1,288
      X(I,J)=NUM(I,J)*4.94
      IF((J.EQ.1).AND.(I.EQ.1))GO TO 855
      IF((J.EQ.1).AND.(I.GE.2))GO TO 860
      Z(I,J)= Z(I,J-1)+X(I,J)-ALPHA
      GO TO 880
  855 IF (NPLAN.EQ.4) ALPHA=ALPHA1
      Z(I,J)=X(I,J)-ALPHA
      GO TO 880
  860 Z(I,J)= Z(I-1 ,288)+X(I,J)-ALPHA
  880 IF(Z(I,J).LT.0.0)Z(I,J)=0.0
      IF(ZMAX(M,L).LT.Z(I,J)) ZMAX(M,L)=Z(I,J)
      TANK=Z(I,J)
      IF(NPLAN.EQ.1) GO TO 1000
      IF(NPLAN.EQ.2) GO TO 1000
      IF(NPLAN.EQ.3)CALL PLAN3(TANK,ALPHA1,ALPHA,&900)
      IF(NPLAN.EQ.4)CALL PLAN4(TANK,ALPHA1,ALPHA,ZSTOP,
     CZSTART,&900)
      IF(NPLAN.EQ.5) CALL PLAN5(ALPHA1,ALPHA,TSTOP,&900)
  900 CONTINUE
 1000 CONTINUE
 1500 CONTINUE
*                                                                  *
THE WEEKLY PROCESSING TIME IS THEN COMPUTED
*                                                                  *
      IF(NPLAN.EQ.1) ITIME=2016
      IF(NPLAN.EQ.2) ITIME=0
      IF(NPLAN.EQ.5) ITIME=(288-TSTOP)*7
      TPROSS(M,L)=168.-ITIME/12.
*                                                                  *
IF DESIRED, THE WEEKLY SEWAGE INVENTORY MAY BE PLOTTED.
*                                                                  *
      IF(NODRAW.EQ.0) GO TO 2900
      INDEX=0
      DO 2000 I=1,7
      DO 1900 J=12,288,12
      INDEX=INDEX+1
      YORD(INDEX)=Z(I,J)
 1900 CONTINUE
 2000 CONTINUE
      DO 2100 J=1,168
 2100 XORD(J)=J
      CALL DRAW(168,XORD,YORD,0,0,LABEL,TITLE,20.0,300.0,0,0
     1LAST)
*                                                                  *
REALIZATION OF EITHER SEWAGE OR ARRIVALS FOR EACH FIVE MIN-
UTE INTERVAL MAY THEN BE PRINTED AS DESIRED. Z VALUES ARE
CUMMULATIVE HOURLY
*                                                                  *
```

```
 2900 IF(NOPRIN.LT.2) GO TO 5000
      WRITE(6,3500)ZMAX(M,L),ALPHA1,TPROSS(M,L)
 3500 FORMAT('0',20X,'ZMAX=',F8.1,10X,'PROCESSING RATE = ',
     CF6.1,10X,'PROCESSING TIME = ',F7.2,//)
 2950 IF (NOPRIN.LT.3) GO TO 5000
      WRITE(6,3000)((Z(I,J),I=1,7),J=12,288,12)
 3000 FORMAT('0  Z MATRIX'//(1X,7(F8.1,4X)))
 4000 IF(NOPRIN.LT.4) GO TO 5000
      WRITE(6,3100)((X(I,J),I=1,7),J=1,288)
 3100 FORMAT('1  X MATRIX'//(1X,7(F5.2,3X)))
      WRITE(6,3200)((NUM(I,J),I=1,7),J=1,288)
 3200 FORMAT('1  ARRIVALS MATRIX'//(1X,7(I2,3X)))
 5000 CONTINUE
 6000 CONTINUE
*                                                                     *
STATISTICS ARE THEN COMPUTED FOR MAXIMUM SEWAGE LEVEL AND
FOR PROCESSING TIME. THE FINAL RESULTS ARE THEN PRINTED
*                                                                     *
      DIMENSION ZSUM(20),ZAVE(20),ZVSUM(20),TSUM(20),TAVE(20
     C),TVSUM(20),ZVAR(20),TVAR(20)
      DO 7200 J=1,M
      ZSUM(J)=0.
      ZVSUM(J)=0.
      TSUM(J)=0.
      TVSUM(J)=0.
      DO 7000 I=1,L
      ZSUM(J)=ZSUM(J)+ZMAX(J,I)
      TSUM(J)=TSUM(J)+TPROSS(J,I)
 7000 CONTINUE
      ZAVE(J)=ZSUM(J)/L
      TAVE(J)=TSUM(J)/L
      DO 7100 I=1,L
      ZVSUM(J)=ZVSUM(J)+((ZMAX(J,I)-ZAVE(J))**2)
      TVSUM(J)=TVSUM(J)+((TPROSS(J,I)-TAVE(J))**2)
      ZVAR(J)=ZVSUM(J)/L
      TVAR(J)=TVSUM(J)/L
 7100 CONTINUE
 7200 CONTINUE
      WRITE(6,8000) NPLAN
 8000 FORMAT('1    ZMAX MATRIX FOR POLICY NO. ',I2//)
      DO 8200 J=1,L
      WRITE(6,8100)(ZMAX(I,J),I=1,M)
 8100 FORMAT(1X,10(F8.2,3X))
 8200 CONTINUE
      WRITE(6,8500)(ZAVE(J),J=1,M)
 8500 FORMAT('0    AVERAGE ZMAX'//(3X,10(F8.2,2X)))
      WRITE(6,8600)(ZVAR(J),J=1,M)
 8600 FORMAT('0    ZMAX VARIANCE '//(3X,10(F10.2,1X)))
      WRITE(6,9000) NPLAN
 9000 FORMAT('1   PROCESSING TIME MATRIX FOR POLICY NO. ',
     CI2//)
      DO 9200 J=1,L
      WRITE(6,8150)(TPROSS(I,J),I=1,M)
 8150 FORMAT(1X,10(F7.2,3X))
 9200 CONTINUE
      WRITE(6,9300)(TAVE(J),J=1,M)
 9300 FORMAT('0    AVERAGE TIME'//(3X,10(F6.2,2X)))
      WRITE(6,9400)(TVAR(J),J=1,M)
 9400 FORMAT('0    TIME VARIANCE '//(3X,10(F10.2,1X)))
      STOP
      END
*                                                                     *
THE FOLLOWING SUBROUTINE GENERATES POISSON VARIATES FOR EACH
FIVE MINUTE INCREMENT. A TABLE LOOK-UP METHOD WAS USED
*                                                                     *
```

```
      SUBROUTINE POISSN(PLAM,IX,N)
      COMMON I,J,ITIME,NOPRIN
      INTEGER N
      A=EXP(-PLAM)
      B=A*PLAM+A
      C=(A*PLAM**2)/2+B
      D=(A*PLAM**3)/6+C
      E=(A*PLAM**4)/24+D
      F=(A*PLAM**5)/120+E
      G=(A*PLAM**6)/720+F
      H=(A*PLAM**7)/5040.+G
      P=(A*PLAM**8)/40320.+H
    5 CALL RANDU(IX,IY,YFL)
      IX=IY
      R= YFL
      IF(R.LE.A) GO TO 6
      IF (R.LE.B) GO TO 7
      IF (R.LE.C) GO TO 8
      IF (R.LE.D) GO TO 9
      IF (R.LE.E) GO TO 10
      IF (R.LE.F) GO TO 11
      IF (R.LE.G) GO TO 12
      IF (R.LE.H) GO TO 13
      IF (R.LE.P) GO TO 15
      N=9
      GO TO 14
    6 N=0
      GO TO 14
    7 N=1
      GO TO 14
    8 N=2
      GO TO 14
    9 N=3
      GO TO 14
   10 N=4
      GO TO 14
   11 N=5
      GO TO 14
   12 N=6
      GO TO 14
   13 N=7
      GO TO 14
   15 N=8
   14 RETURN
      END


      SUBROUTINE PLAN3(TANK,ALFA1,RATE,*)
*                                                                        *
THIS POLICY PROCESSES SEWAGE UNTIL 1600 AFTER WHICH TIME IT
THEN EXAMINES THE LEVEL OF THE TANK AND IF BELOW 50 GAL.IT
STOPS PROCESSING UNTIL 0500 THE FOLLOWING DAY. ON WEEKENDS
PROCESSING STOPS ANYTIME THE LEVEL IN THE TANK REACHES 50 GA
*                                                                        *
      COMMON I,J,ITIME,NOPRIN
      IF((I.EQ.1).AND.(J.EQ.1)) IFLAG=0
      IF(NOPRIN.LT.2) GO TO 6
      IF((I.EQ.1).AND.(J.EQ.1)) WRITE(6,5)
    5 FORMAT('0      PROCESSING POLICY  NO.3 WAS USED ON THIS
     CRUN',//)
    6 IF((J.EQ.1).AND.(IFLAG.EQ.1)) ITIME=ITIME+288-JSTOP
      IF(J.EQ.1) IFLAG=0
      IF(I.LE.5) GO TO 10
      IF(TANK.LE.50.) GO TO 30
      IF((RATE.LT.0.01).AND.(TANK.GE.500.)) GO TO 20
      GO TO 40
   10 IF(J.LE.132) GO TO 40
      IF(TANK.LE.50.) GO TO 30
```

```
      GO TO 40
   20 RATE=ALFA1
      IF(IFLAG.EQ.0) GO TO 40
      ITIME=ITIME+J-JSTOP
      IF(NOPRIN.LT.2) GO TO 26
      WRITE(6,25)I,J
   25 FORMAT('    CONTINUED PROCESSING AT T=',I1,'-',I3,//)
   26 IFLAG=0
      GO TO 40
   30 RATE=0.0
      IF(IFLAG.EQ.1)GO TO 40
      JSTOP=J
      IF(NOPRIN.LT.2) GO TO 36
      WRITE(6,35)I,J
   35 FORMAT('0     STOPPED PROCESSING AT T=',I1,'-',I3,//)
   36 IFLAG=1
   40 IF((I.EQ.7).AND.(J.EQ.288)) GO TO 45
      GO TO 50
   45 IF(IFLAG.EQ.1) ITIME=ITIME+288-JSTOP
   50 RETURN1
      END


      SUBROUTINE PLAN4(TANK,ALFA1,RATE,STOP,START,*)
*                                                           *
THIS IS A LEVEL CONTROL POLICY WHICH CONTINUOUSLY EXAMINES
T&& L&OEL OF SEWAGE IN THE TANK.IF BELOW SOME SET LEVEL
(ZSTOP) THEN PROCESSING STOPS UNTIL THE SEWAGE LEVEL REACHES
SOME UPPER VALUE (ZSTART) AT WHICH TIME PROCESSING CONTINUES
*                                                           *
      COMMON I,J,ITIME,NOPRIN
      IF((I.EQ.1).AND.(J.EQ.1)) IFLAG=0
      IF(NOPRIN.LT.2) GO TO 6
      IF((I.EQ.1).AND.(J.EQ.1)) WRITE(6,5)
    5 FORMAT('0    PROCESSING POLICY  NO.4 WAS USED ON THIS
     CRUN',//)
    6 IF((J.EQ.1).AND.(IFLAG.EQ.1)) ITIME=ITIME+288-JSTOP
      IF(J.EQ.1) JSTOP=0
      IF(TANK.GT.STOP) GO TO 20
      RATE=0.0
      IF(IFLAG.EQ.1)GO TO 40
      JSTOP=J
      IF(NOPRIN.LT.2) GO TO 11
      WRITE(6,10)I,J
   10 FORMAT('0     STOPPED PROCESSING AT T=',I1,'-',I3,//)
   11 IFLAG=1
      GO TO 40
   20 IF(TANK.LE.START) GO TO 40
      RATE=ALFA1
      IF(IFLAG.EQ.0) GO TO 40
      ITIME=ITIME+J-JSTOP
      IF(NOPRIN.LT.2) GO TO 31
      WRITE(6,30)I,J
   30 FORMAT('    CONTINUED PROCESSING AT T=',I1,'-',I3,//)
   31 IFLAG=0
   40 IF((I.EQ.7).AND.(J.EQ.288)) GO TO 45
      GO TO 50
   45 IF(IFLAG.EQ.1) ITIME=ITIME+288-JSTOP
   50 RETURN1
      END


      SUBROUTINE PLAN5(ALFA1,RATE,TIME,*)
*                                                           *
THIS IS A TIME CONTROL POLICY. IT ALLOWS PROCESSING FOR A
FIXED PORTION OF THE DAY ONLY
*                                                           *
      COMMON I,J,ITIME,NOPRIN
      INTEGER TIME
      IF(NOPRIN.LT.2) GO TO 6
      IF((I.EQ.1).AND.(J.EQ.1)) WRITE(6,5)
    5 FORMAT('0    PROCESSING POLICY  NO.5 WAS USED ON THIS
```

```
     CRUN',//)
   6 IF(J.LE.TIME) GO TO 10
      RATE=0.0
  10 RETURN1
      END
```

```
      SUBROUTINE RANDU(IX,IY,YFL)
*                                                                    *
THIS ROUTINE GENERATES RANDOM NUMBERS FOR USE IN THE MAIN
PROGRAM
*                                                                    *
      COMMON I,J,ITIME,NOPRIN
      IY=IX*65539
      IF(IY)5,6,6
   5 IY=IY+2147483647+1
   6 YFL=IY
      YFL=YFL*.4656613E-9
      RETURN
      END
```

Note: Comment cards denoted by and including * should be removed prior to running programs.

```
*                                                          *
*                  TANK SIMULATION TWO                     *
************************************************************
THIS SIMULATION WAS DEVELOPED BY JOHN O MINER,JR TO DESCRIBE
THE PROCESS OF GENERATING AND PROCESSING SEWAGE ABOARD A
NAVAL SHIP. IT ASSUMES THAT THE DAILY AVERAGE SEWAGE GENERA-
TION RATE PER CAPITA IS BETA DISTRIBUTED OVER THE INTERVAL
11.3 GAL/MAN/DAY TO 20.0 GAL/MAN/DAY. IT GENERATES DAILY
OBSERVATIONS OF THE DAILY RATE AND CONVERTS THEM TO HOURLY
VARIATES BASED ON AN EMPIRICAL ARRIVAL DISTRIBUTION. THE
HOURLY OBSERVATIONS THEN SERVE AS THE INPUT TO A SEWAGE
HOLDING TANK FROM WHICH THE SEWAGE IS PROCESSED ACCORDING TO
ONE OF FIVE SAMPLE PROCESSING POLICIES WHICH ARE ARE REPRE-
SENTED BY INDIVIDUAL SUBROUTINES. OVER A WEEK'S PERIOD OF
SIMULATED TIME, THE MAXIMUM SEWAGE LEVEL OBSERVED FOR UP TO
100 REPLICATES IS RECORDED ALONG WITH THE TOTAL PROCESSING
TIME. STATISTICS ARE THEN COMPUTED AND THE THE RESULTS PRINT
ED ACCORDING TO ONE OF FOUR POSSIBLE PRINT ROUTINES.
************************************************************
*                                                          *
*                                                          *
THE FOLLOWING STATEMENTS INITIALZE THE PROGRAM. THE DATA
STATEMENT READS IN THE CONVERSION FACTORS FOR THE EMPIRICAL
DISTRIBUTION
*                                                          *
      COMMON IX,I,J,ITIME,NOPRIN
      DIMENSION CONVER(24),X(7,24),Z(7,24)
      DIMENSION DAILY(7),HOURLY(7),Y(7),Y1(7)
      DIMENSION XORD(168),YORD(168)
      DIMENSION ZMAX(10,100),IPROSS(10,100)
      REAL*8 TITLE(12)/'TANKSIM2',11*'        '/
      REAL LABEL/'    '/
      DATA CONVER/.756,1.97,1.82,.963,.812,1.09,1.80,1.61,.9
     D63,.825,1.47,1.69,1.31,1.04,.839,.770,.880,.770,.687,
     E.495,.344,.234,.440,.413/
*                                                          *
THE PARAMETERS TO BE TESTED ARE THEN READ IN
*                                                          *
      READ(5,20)MEN,NPLAN,ALPHA2,ZSTOP,ZSTART,NOPRIN,NODRAW
     C,KSTOP
   20 FORMAT(I3,I2,F4.1,F5.2,F5.1,3I2)
*                                                          *
THE FIVE POLICIES ARE THEN TESTED SEQUENTIALLY FOR 100 REP-
LICATIONS EACH. THE SAME RANDOM NUMBER SEED IS USED FOR EACH
POLICY
*                                                          *
      DO 9999 NRUN=1,4
      IX=21111111
      NPLAN=NPLAN+1
      ALPHA1=ALPHA2
*                                                          *
EACH POLICY IS TESTED FOR NINE RATES IN INCREMENTS OF 10 GAL
*                                                          *
      DO 6000 M=1,9
      ALPHA1=ALPHA1+10.0
      DO 5000 L=1,100
      IX=IX+112
      IF(NOPRIN.LT.2) GO TO 155
      WRITE(6,150)L
  150 FORMAT('1',20X,'RUN NO.  ',I2,//)
  155 ZMAX(M,L)=0.0
      ALPHA=0.0
      ITIME=0
      DO 30 I=1,7
```

```
      DO 25 J=1,24
      Z(I,J)=0.0
      X(I,J) = 0.0
   25 CONTINUE
   30 CONTINUE
*                                                           *
SEVEN BETA VARIATES ARE GENERATED FOR EACH DAY OF THE WEEK
*                                                           *
      DO 50 I=1,7
      Y(I)=GAM(4.3,1.,1.)
      Y1(I)=GAM(5.7,1.,1.)
      BETA2=Y(I)/(Y(I)+Y1(I))
      DAILY(I)=BETA2*8.7+11.3
  50  CONTINUE
      IF(NOPRIN.LT.2) GO TO 56
      WRITE(6,55)(DAILY(I),I=1,7)
   55 FORMAT('0 DAILY BETA VARIATES: '//(1X,7(F5.2,1X)))

*                                                           *
THE DAILY VARIATES ARE CONVERTED TO HOURLY VALUES AND
THEN TRANSFORMED TO THE EMPIRICAL DISTRIBUTION
*                                                           *
   56 DO 60 I=1,5
   60 HOURLY(I)=(DAILY(I)*MEN)/24
      DO 65 I=6,7
   65 HOURLY(I)=(DAILY(I)*MEN/4)/24
      DO 80 I=1,7
      DO 70 J=1,24
      X(I,J)=CONVER(J)*HOURLY(I)
   70 CONTINUE
   80 CONTINUE
      DO 1500 I=1,7
      IF((NPLAN.EQ.1).OR.(NPLAN.EQ.4)) GO TO 90
*                                                           *
THIS SECTION THEN TAKES THE SEWAGE INPUT THAT HAS BEEN GEN-
ERATED AND PROCESSES IT ACCORDING TO ONE OF THE FIVE POLIC-
IES. THE RESULTS FOR EACH HOUR ARE RECORDED IN A MATRIX.
THE VALUE FOR THE MAXIMUM SEWAGE LEVEL IS ALSO RECORDED FOR
EACH WEEKLY CYCLE
*                                                           *
      ALPHA=ALPHA1
   90 DO 1000 J=1,24
      IF((J.EQ.1).AND.(I.EQ.1))GO TO 855
      IF((J.EQ.1).AND.(I.GE.2))GO TO 860
      Z(I,J)= Z(I,J-1)+X(I,J)-ALPHA
      GO TO 880
  855 IF (NPLAN.EQ.4) ALPHA=ALPHA1
      Z(I,J)=X(I,J)-ALPHA
      GO TO 880
  860 Z(I,J)= Z(I-1 ,24 )+X(I,J)-ALPHA
  880 IF(Z(I,J).LT.0.0)Z(I,J)=0.0
      IF(ZMAX(M,L).LT.Z(I,J)) ZMAX(M,L)=Z(I,J)
      TANK=Z(I,J)
      IF(NPLAN.EQ.1) GO TO 1000
      IF(NPLAN.EQ.2) GO TO 1000
      IF(NPLAN.EQ.3)CALL PLAN3(TANK,ALPHA1,ALPHA,&900)
      IF(NPLAN.EQ.4)CALL PLAN4(TANK,ALPHA1,ALPHA,ZSTOP,
     1ZSTART,&900)
      IF(NPLAN.EQ.5) CALL PLAN5(ALPHA1,ALPHA,KSTOP,&900)
  900 CONTINUE
 1000 CONTINUE
 1500 CONTINUE
*                                                           *
THE PROCESSING TIME IS ALSO COMPUTED AND RECORDED
*                                                           *
      IF (NPLAN.EQ.1) ITIME=168
      IF(NPLAN.EQ.2) ITIME=0
      IF(NPLAN.EQ.5) ITIME=(24-KSTOP)*7
      IPROSS(M,L)=168-ITIME
```

```
*                                                                      *
IF DESIRED THE WEEKLY SEWAGE LEVEL CAN BE PLOTTED FOR EACH
HOUR
*                                                                      *
      IF(NODRAW.EQ.0) GO TO 2900
      N=0
      DO 2000 I=1,7
      DO 1900 J=1,24
      N=N+1
      YORD(N)=Z(I,J)
 1900 CONTINUE
 2000 CONTINUE
      DO 2100 J=1,168
 2100 XORD(J)=J
      CALL DRAW(168,XORD,YORD,0,0,LABEL,TITLE,20.0,300.0,0,0
     1LAST)
*                                                                      *
THE RESULTS CAN THEN BE PRINTED TO THE EXTENT DESIRED
*                                                                      *
 2900 IF(NOPRIN.LT.2) GO TO 2950
      WRITE(6,3500)ZMAX(M,L),ALPHA1,IPROSS(M,L)
 3500 FORMAT('0',20X,'ZMAX=',F8.1,10X,'PROCESSING RATE = ',
     1F6.1,10X,'PROCESSING TIME = ',I3,//)
 2950 IF(NOPRIN.LT.3) GO TO 5000
      WRITE(6,3000)((Z(I,J),I=1,7),J=1,24)
 3000 FORMAT('1  Z MATRIX'//(1X,7(F8.1,4X)))
      WRITE(6,3100)((X(I,J),I=1,7),J=1,24)
 3100 FORMAT('0  X MATRIX'//(1X,7(F8.2,3X)))
 5000 CONTINUE
 6000 CONTINUE
*                                                                      *
THIS ROUTINE COMPUTES THE AVERAGE VALUES AND VARIANCES FOR
THE MAXIMUM SEWAGE LEVEL AND THE WEEKLY PROCESSING TIME
*                                                                      *
      DIMENSION ZSUM(20),ZAVE(20),ZVSUM(20),TSUM(20),
     1TAVE(20),TVSUM(20),ZVAR(20),TVAR(20)
      DO 7200 J=1,M
      ZSUM(J)=0.
      ZVSUM(J)=0.
      TSUM(J)=0.
      TVSUM(J)=0.
      DO 7000 I=1,L
      ZSUM(J)=ZSUM(J)+ZMAX(J,I)
      TSUM(J)=TSUM(J)+IPROSS(J,I)
 7000 CONTINUE
      ZAVE(J)=ZSUM(J)/L
      TAVE(J)=TSUM(J)/L
      DO 7100 I=1,L
      ZVSUM(J)=ZVSUM(J)+((ZMAX(J,I)-ZAVE(J))**2)
      TVSUM(J)=TVSUM(J)+((IPROSS(J,I)-TAVE(J))**2)
      ZVAR(J)=ZVSUM(J)/L
      TVAR(J)=TVSUM(J)/L
 7100 CONTINUE
 7200 CONTINUE
      WRITE(6,8000) NPLAN
 8000 FORMAT('1     ZMAX MATRIX FOR POLICY NO. ',I2//)
      DO 8200 J=1,L
      WRITE(6,8100)(ZMAX(I,J),I=1,M)
 8100 FORMAT(1X,10(F8.2,3X))
 8200 CONTINUE
      WRITE(6,8500)(ZAVE(J),J=1,M)
 8500 FORMAT('0     AVERAGE ZMAX'//(3X,10(F8.2,2X)))
      WRITE(6,8600)(ZVAR(J),J=1,M)
 8600 FORMAT('0     ZMAX VARIANCE '//(3X,10(F10.2,1X)))
      WRITE(6,9000)
 9000 FORMAT('1    PROCESSING TIME MATRIX'//)
      DO 9200 J=1,L
      WRITE(6,8150)(IPROSS(I,J),I=1,M)
 8150 FORMAT(1X,10(I3,3X))
 9200 CONTINUE
      WRITE(6,9300)(TAVE(J),J=1,M)
```

```
 9300 FORMAT('0    AVERAGE TIME'//(3X,10(F6.2,2X)))
      WRITE(6,9400)(TVAR(J),J=1,M)
 9400 FORMAT('0    TIME VARIANCE '//(3X,10(F10.2,1X)))
 9999 CONTINUE
      STOP
      END


      FUNCTION GAM(ALFA,BETA,START)
C NON INTEGER GAMMA GENERATOR DEVELOPED BY D T PHILLIPS
      COMMON IX,I,J,ITIME,NOPRIN
      IF(START.GT.1.5) GO TO 58
      X3=1.0
      IF(ALFA.LE.2.0) GO TO 1
      IF(ALFA.LE.5.0) GO TO 2
      GO TO 3
    1 B=0.2177+(2.10299768*ALFA)-(4.34611961*ALFA**2)+
     C(6.00914764*ALFA**
     C3)-(3.95097728*ALFA**4)+(0.97279251*ALFA**5)
      GO TO 4
    2 B=0.64350+(0.45839602*ALFA)-(0.02952801*ALFA**2)+
     C(0.00172718*ALFA*
     C*3)-(0.00005810*ALFA**4)+(0.00000082*ALFA**5)
      GO TO 4
    3 B=1.33408+(0.22499991*ALFA)-(0.00230695*ALFA**2)+
     C(0.00001623*ALFA*
     C*3)-(0.00000006*ALFA**4)
    4 S=1.0+(1.0/B)
      START=5.0
   12 IF(S-1.0)110,60,15
   15 S=S-1.0
      X3=X3*S
      GO TO 12
  110 GY=1.0+S*(-0.5771017+S*(0.985854+S*(-0.8764218+S*(0.83
     1S*(-0.5684729+S*(0.2548205+S*(-0.05149930)))))))
      X3=X3*GY
   58 A=(X3/(ALFA*BETA))**B
      B=1.0/B
      A=1.0/A
   60 CALL RANDU(IX,IY,YFL)
      IX=IY
      GAM=(-A*ALOG(YFL))**B
      RETURN
      END


      SUBROUTINE PLAN3(TANK,ALFA1,RATE,*)
*                                                          *
THIS POLICY PROCESSES SEWAGE UNTIL 1600 AFTER WHICH TIME IT
THEN EXAMINES THE LEVEL OF THE TANK AND IF BELOW 50 GAL.IT
STOPS PROCESSING UNTIL 0500 THE FOLLOWING DAY. ON WEEKENDS
PROCESSING STOPS ANYTIME THE LEVEL IN THE TANK REACHES 50 GA
*                                                          *
      COMMON IX,I,J,ITIME,NOPRIN
      IF((I.EQ.1).AND.(J.EQ.1)) IFLAG=0
      IF(NOPRIN.LT.2) GO TO 6
      IF((I.EQ.1).AND.(J.EQ.1)) WRITE(6,5)
    5 FORMAT('0    PROCESSING POLICY  NO.3 WAS USED ON THIS
     CRUN',//)
    6 IF((J.EQ.1).AND.(IFLAG.EQ.1)) ITIME=ITIME+24-JSTOP
      IF(J.EQ.1) IFLAG=0
      IF(I.LE.5) GO TO 10
      IF(TANK.LE.50.) GO TO 30
      IF((RATE.LT.0.01).AND.(TANK.GE.500.)) GO TO 20
      GO TO 40
   10 IF(J.LE.11) GO TO 40
      IF(TANK.LE.50.) GO TO 30
      GO TO 40
   20 RATE=ALFA1
      IF(IFLAG.EQ.0) GO TO 40
      ITIME=ITIME+J-JSTOP
      IF(NOPRIN.LT.2) GO TO 26
```

```
      WRITE(6,25)I,J
   25 FORMAT('    CONTINUED PROCESSING AT T=',I1,'-',I2,//)
   26 IFLAG=0
      GO TO 40
   30 RATE=0.0
      IF(IFLAG.EQ.1)GO TO 40
      JSTOP=J
      IF(NOPRIN.LT.2) GO TO 36
      WRITE(6,35)I,J
   35 FORMAT('0     STOPPED PROCESSING AT T=',I1,'-',I2,//)
   36 IFLAG=1
   40 IF((I.EQ.7).AND.(J.EQ.24)) GO TO 45
      GO TO 50
   45 IF(IFLAG.EQ.1) ITIME=ITIME+24-JSTOP
   50 RETURN1
      END

      SUBROUTINE PLAN4(TANK,ALFA1,RATE,STOP,START,*)
*                                                            *
THIS IS A LEVEL CONTROL POLICY WHICH CONTINUOUSLY EXAMINES
THE LEVEL OF SEWAGE IN THE TANK.IF BELOW SOME SET LEVEL
(ZSTOP) THEN PROCESSING STOPS UNTIL THE SEWAGE LEVEL REACHES
SOME UPPER VALUE (ZSTART) AT WHICH TIME PROCESSING CONTINUES
*                                                            *
      COMMON IX,I,J,ITIME,NOPRIN
      IF((I.EQ.1).AND.(J.EQ.1)) IFLAG=0
      IF(NOPRIN.LT.2) GO TO 6
      IF((I.EQ.1).AND.(J.EQ.1)) WRITE(6,5)
    5 FORMAT('0    PROCESSING POLICY  NO.4 WAS USED ON THIS
     CRUN',//)
    6 IF((J.EQ.1).AND.(IFLAG.EQ.1)) ITIME=ITIME+24-JSTOP
      IF(J.EQ.1) JSTOP=0
      IF(TANK.GT.STOP) GO TO 20
      RATE=0.0
      IF(IFLAG.EQ.1)GO TO 40
      JSTOP=J
      IF(NOPRIN.LT.2) GO TO 11
      WRITE(6,10)I,J
   10 FORMAT('0     STOPPED PROCESSING AT T=',I1,'-',I2,//)
   11 IFLAG=1
      GO TO 40
   20 IF(TANK.LE.START) GO TO 40
      RATE=ALFA1
      IF(IFLAG.EQ.0) GO TO 40
      ITIME=ITIME+J-JSTOP
      IF(NOPRIN.LT.2) GO TO 35
      WRITE(6,30)I,J
   30 FORMAT('    CONTINUED PROCESSING AT T=',I1,'-',I2,//)
   35 IFLAG=0
   40 IF((I.EQ.7).AND.(J.EQ.24)) GO TO 45
      GO TO 50
   45 IF(IFLAG.EQ.1) ITIME=ITIME+24-JSTOP
   50 RETURN1
      END

      SUBROUTINE PLAN5(ALFA1,RATE,KTIME,*)
*                                                            *
THIS IS A TIME CONTROL POLICY. IT ALLOWS PROCESSING FOR A
FIXED PORTION OF THE DAY ONLY
*                                                            *
      COMMON IX,I,J,ITIME,NOPRIN
      IF(NOPRIN.LT.2) GO TO 6
      IF((I.EQ.1).AND.(J.EQ.1)) WRITE(6,5)
    5 FORMAT('0    PROCESSING POLICY  NO.5 WAS USED ON THIS
     CRUN',//)
    6 IF(J.LE.KTIME) GO TO 10
      RATE=0.0
   10 RETURN1
      END
```

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13. ABSTRACT

An investigation into the problems of economically processing sewage on board Naval ships resulted in the development of two computer simulations employing Monte Carlo analysis to describe the generation of sewage. Simulation one was based on a non-homogeneous Poisson process. For simulation two, an empirical distribution describing the arrival behavior of sewage to the holding/processing unit over a 24 hour period was applied to known data on sewage generation.

Results of the two simulations were compatible with one another. Aside from pointing out a most feasible combination of holding tank capacity, processor rate and processing policy, the simulations also indicated that a revision of the Navy's design parameter for the daily per capita sewage generation rate was in order. The simulations were designed so that use by others with their own data would be an easy matter.

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